FINAL REPORT AUG 13 2001

1999 Project Abstract
For the period Ending June 30, 2001

PR0JECT TITLE: Diversifying Agriculture for Environmental, Economic, and Social Benefits

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Fund: Minnesota Environment and Natural Resources Trust Fund
Legal Citation: ML 1999, Chap. 231, Sec. 16 , Subd. 007f .

Appropriation amount: $400,000

We evaluated cover crops, agroforestry, and native perennial legumes and have identified some approaches to improve the economic and environmental outcomes of cropping systems. In northern Minnesota, systems with perennial ryegrass interseeded into soybeans, wheat, and flax with perennial ryegrass seed harvested the following year were more profitable than continuous wheat or a soybean/wheat rotation. Intercropping of alfalfa, red clover, and vetch with wheat did not reduce the incidence of Fusarium head blight of wheat. In southern Minnesota, winter rye cover cropping following corn in a corn-soybean system reduced nitrate-nitrogen losses an average of 60% compared to a conventional corn-soybean rotation. Superior winter rye varieties were identified for use in nitrogen scavenging. Nitrogen scavenging crops can improve the environment for all citizens. Yellow sweetclover, mammoth red clover, and non-dormant alfalfa produced significant biomass and N accumulation when interseeded with a small grain crop and can be used to reduce synthetic N fertilizer use by producers. Living mulch systems using Kura clover can be effective at providing ground cover and suppressing weeds therefore reducing erosion and herbicide use. Improved hybrid hazelnuts have potential as a new woody nut crop in southern and central Minnesota. Hazelnuts were successfully established and survived a winter in diverse environments. Controlling competing vegetation enhanced hazelnut establishment. Collections and populations of Illinois bundleflower and false indigo, two native perennial legumes, were developed and evaluated. These legumes could be the basis of a new seed production industry and can be used for prairie restoration and grazing systems. Establishment of these legumes for use in grazing systems is challenging unless competition with cool season grasses and weeds is minimized. Research was conducted in 30 diverse environments and the information transferred to 2000 producers at field days, meetings, and workshops. Informational fact sheets, scientific publication, and a web site were developed.

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Date of Report: July 1, 2001
LCMR Final Work Program Report
Date of Work Program Approval: June 16, 1999
Project Completion Date: June 30, 2001

I. PROJECT TITLE: Diversifying Agriculture for Environmental, Economic, and Social Benefits.
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Total Biennial Project Budget:

$ LCMR:	$400,000.00
- $LCMR Spent	$357,923.20
= $LCMR Balance:	$ 42,076.80

A. Legal Citation: ML 1999, Chap. 231, Sec. 16 , Subd. 007f .

Appropriation Language:
Diversifying Agriculture for Environmental, Economic, and Social Benefits.

"$200,000 from the first year and $200,000 the second year are from the environmental trust fund to the University of Minnesota to research new plant material and crop management systems for diversification".

B. Status of Match Requirement: The University of Minnesota has provided $115,000 in in-kind match.

II. AND III. FINAL PROJECT SUMMARY:

We evaluated cover crops, agroforestry, and native perennial legumes and have identified some approaches to improve the economic and environmental outcomes of cropping systems. In northern Minnesota, systems with perennial ryegrass interseeded into soybeans, wheat, and flax with perennial ryegrass seed harvested the following year were more profitable than continuous wheat or a soybean/wheat rotation. Intercropping of alfalfa, red clover, and vetch with wheat did not reduce the incidence of Fusarium head blight of wheat. In southern Minnesota, winter rye cover cropping following corn in a corn-soybean system reduced nitrate-nitrogen losses an average of 60% compared to a conventional corn-soybean rotation. Superior winter rye varieties were identified for use in nitrogen scavenging. Nitrogen scavenging crops can improve the environment for all citizens. Yellow sweetclover, mammoth red clover, and non-dormant alfalfa produced significant biomass and N accumulation when interseeded with a small grain crop and can be used to reduce synthetic N fertilizer use by producers. Living mulch systems using Kura clover can be effective at providing ground cover and suppressing weeds therefore reducing erosion and herbicide use. Improved hybrid hazelnuts have potential as a new woody nut crop in southern and central Minnesota. Hazelnuts were successfully established and survived a winter in diverse environments. Controlling competing vegetation enhanced hazelnut establishment. Collections and populations of Illinois bundleflower and false indigo, two native perennial legumes, were developed and evaluated. These legumes could be the basis of a new seed production industry and can be used for prairie restoration and grazing systems. Establishment of these legumes for use in grazing systems is challenging unless competition with cool season grasses and weeds is minimized. Research was conducted in 30 diverse environments and the information transferred to 2000 producers at field days, meetings, and workshops. Informational fact sheets, scientific publication, and a web site were developed.

IV. OUTLINE OF PROJECT RESULTS:

Result 1. Cover crops for Northwestern Minnesota

LCMR Budget:	$42,000.00
Balance:	$11,283.27

In-Kind match of $15,000

Unspent balance can be attributed an over estimation of expenses by researchers, less travel costs, and the failure of the farmer to submit an invoice for payment. All research was completed except the corn phase of Objective 1 (see explanation below).

Objective 1. Identify hairy vetch ecotypes that positively influence crop productivity.
Four vetch ecotypes were evaluated in this experiment for performance as components in corn/ soybean, and in small grain/corn rotations. Vetch ecotypes evaluated include a Northwest Minnesota ecotype (source, J. Derosier) adapted to conditions in Red Lake Falls County, a Southwest Minnesota ecotype (source, W. Schmidt) adapted to conditions Lac Qui Parle County, a Nebraska ecotype (source White Seed, Neligh, NE) and a California vetch (Lana, woolypod vetch).

Based on previous research, an August vetch seeding date was considered to be optimal because 1) vetch established in the fall will overwinter and will produce additional biomass the following spring, 2) fall seeded vetch does not compete with the standing crop and would not interfere with harvest, and 3) the growth pattern of fall seeded vetch allows efficient use of end of season water and nitrogen.

On August 15 2000, vetch ecotypes were broadcast into standing soybeans and into disked flax stubble. Soil conditions were dry and germination of the vetch was delayed. The vetch began germinating in late October and early November. The seedlings were not established well enough to withstand the onset of sub-freezing temperatures and the winter kill rate of the late germinating plants was high. Surviving vetch stands in May of 2001 were sparse. Vetch seeds that did not germinate in the previous fall germinated in the spring of 2000. However by late-May of 2001 the vetch biomass was too low to proceed with the experiment without compromising the productivity of the corn crop due to late planting.

Ecotype differences: There is some evidence of differences among ecotypes in fall and spring growth rate, ease of establishment, and overwintering ability. When vetches were seeded into wheat stubble, we found that the Northwest and Southwest MN ecotypes had significantly higher (LSD.10) late fall stands (34,709 and 36,734 plants acre$^{-1)}$, than did the Nebraska ecotype or Lana vetch, (28,042 and 27,061 plants acre^{-1}) in wheat stubble. The Southwest MN ecotype produced significantly (LSD.10) greater stands than Northwest MN, Nebraska, and Lana ecotypes when broadcast seeded into standing soybean, 28,779 plants acre^{-1}, vs. 20,266, 16,434, and 22,025 plants acre^{-1}, respectively. Fall biomass production was low for all tested vetches and significant differences were not observed. Over-wintering ability of all tested vetches was poor under prevailing conditions. Northwest MN, Southwest MN and Nebraska ecotypes were not significantly different in spring population density, or in spring biomass production. Lana vetch had significantly lower plant densities and dry matter production in most treatments and showed the lowest over wintering capacity (Appendix, Result 1,Table 1).

Effects of seeding method: In the first vetch planting, fall 1999, populations of vetch broadcast into wheat stubble were significantly higher (31,637 plants acre^{-1}) than populations seeded into standing soybeans (21,876 plants acre^{-1}). By the following spring, however, the populations were not significantly different. In the second vetch planting neither seeding method was found to produce significantly different fall or spring vetch populations. The target vetch population for each treatment was 135,000 plants acre^{-1}. Neither of the seeding methods produced target populations. Poor spring stands were primarily due to the late date at which the vetch began to germinate. The reasoning for seeding vetch in August remains valid, however, in practice we were not able to successfully generate a usable stand of vetch by broadcast seeding in August. Our experimentation illustrates the limiting effects of environment on use of summer and fall seeded cover crops.

Because of the failure to establish vetch in significant populations, we were unable to conduct the second phase of the rotation trials in which corn production was to occur. Without adequate vetch populations, nitrogen contribution and weed and disease development could not be measured.

Grain yield and biomass results are summarized in Appendix, Result 1,Table 4. Interseeding legumes tended to reduce grain yield, with the grain yield of wheat interseeded with hairy vetch being significantly less than the monocrop of wheat. Test weight also was significantly less for the wheat when intercropped with hairy vetch and tended to be lower with the other two legumes when compared to the monocrop of spring wheat. No significant difference was observed for grain protein content. At the time of grain harvest, the above ground biomass of the three legumes was from nearly 400 lbs acre^{-1} for the alfalfa to almost 1200 lbs acre^{-1} for hairy vetch (Table 4). Alfalfa and red clover doubled their biomass from grain harvest to the first killing frost. Hairy vetch, being cut during grain harvest because of it's plant height, recovered generally very well and produced the most biomass for plow down as a green manure at 1288 lbs acre^{-1}. All three legumes averaged around half a ton per acre of green manure at plow down.

The legumes provided no significant reduction in both field severity and VSK score (Appendix, Result 1,Table 5). However, the average scores of all three legumes tended to be lower. Overall disease pressure was light (even under misted conditions in Crookston) in both 1999 and 2000 seasons. Consequently the effect of the legume inter-seeds on Fusarium Head Blight infection could not be determined. The proposed mechanism for disease reduction by legume interseeds is the formation of a barrier of leaves between the soil and the wheat. Observations of the architecture of the leaf canopy produced by the legumes suggested that red clover and alfalfa come closest to producing this idealized leaf barrier. The alfalfa and red clover interseeds grew to a height of about 10-15 inches producing the desired understory to the wheat crop. In contrast, the hairy vetch grew to a height of 35 inches or more, taller than the wheat in some cases, and tended to produce an overstory, which is not satisfactory in this application. Both alfalfa and red clover were generally compatible with wheat growth and development. Red clover tended to produce a denser canopy of leaves, perhaps forming a more effective barrier between soil borne pathogens and wheat. The leaf canopy produced by alfalfa was not as dense as that of red clover, however, alfalfa tended to be the most compatible cover with respect to wheat grain yield.

Grain yield tended to be slightly less when spring wheat was intercropped, significantly less in the case of the vetch interseed. The seeding rate for spring wheat was less than needed to attain recommended plant stand of 28 to 30 plants per square foot. The reason for this was to allow for a better environment for the legumes to establish themselves before the spring wheat canopy would close. This lower seeding rate used for the spring wheat is likely to increase the yield difference between the intercropped spring wheat and a monocrop of wheat if the later is planted at a recommended seeding rate. Of the three legumes used in this experiment, hairy vetch is not suitable for intercropping with spring wheat as it grows too tall when the spring wheat crops matures, hindering in the grain harvest. All three legumes grew after the spring wheat was harvested and provided a small green manure crop at the end of the season.

Finally, weed control was problematic as the combination of pre-plant incorporated trifluralin and/or post-emergence bromoxynil proved inadequate for effective pigweed control (no data presented). Thus, in summary, intercropping of legumes with wheat to reduce Fusarium head blight on wheat and to provide a cost-effective means to produce a green manure crop could not be fully evaluated due to the lack of disease pressure at all sites in both years.

Objective 3: Evaluation of the productivity of alternative rotations with forage seed species. The rotations evaluated were composed of wheat, soybean, or flax for harvest in the first season and interseeded forage species of perennial ryegrass, birdsfoot trefoil, or red clover for seed harvest in the second season. Rotations were evaluated in 1999-2000 (first planting) and again in a repeat experiment in 2000-2001 (second planting).

First season crop performance (both plantings): Wheat was found to be quite tolerant to the presence of all tested interseeded forage species and showed no significant reduction in grain yield (Appendix, Result 1,Table 6). Soybeans also tolerated the presence of interseeded legumes, generally without significant yield reduction. The ryegrass interseed did result in reduction in soybean yield. Flax tolerance to the legume interseeds was fair and significant yield reduction was observed. Flax tolerance to the ryegrass interseed was poor, and probably unacceptable.

Second season forage seed yield performance(first planting): Perennial ryegrass performed well in all rotations producing 825-886 lb acre^{-1} of seed, which was not significantly different than the pure stand yield of 853 lb acre^{-1}. Birdsfoot trefoil seed yields from the flax/trefoil interseed were 207 lb acre^{-1} compared to 210 lb acre^{-1} in the pure birdsfoot trefoil stand. Seed yields observed in the soybean/trefoil treatment, 135 lb acre^{-1}, and wheat/trefoil treatment, 169 lb acre^{-1} were significantly less (LSD.05) than seed yields of pure stand birdsfoot trefoil. Compared to pure stand red clover, with a seed yield 279 lb acre^{-1}, soybean/red clover, wheat/red clover, and flax/red clover treatments produced seed yields that were significantly (LSD.05) lower, but acceptable with 248, 218, and 223 lb acre^{-1}. (Appendix, Result 1,Table 7)

Forage seed yield data for the second planting will be available later in the summer of 2001. For purposes of this report, the relative forage seed yield potential can be forecast by observations of early season stand and vigor presented in Appendix, Result 1,Table 8. Plots with stand ratings of 100% are projected to have yields typical of a good stand under recommended production practices. A rating of 0% would be given to a treatment with no live stand remaining. In general, winter injury was more severe in the second planting than in the first planting. The perennial ryegrass treatments were most severely impacted by winter injury. The wheat/ryegrass treatment appears to have fair ryegrass seed yield potential with a stand rating of 66%. The soybean/ryegrass and flax/ryegrass treatments have poor seed yield potential with stand ratings of 35% and 12%. Winter injury in the pure stand ryegrass treatment was most severe and was assigned a stand rating of 7% of optimum.

The best birdsfoot trefoil treatment appears to be was the flax/trefoil treatment with a stand rating of 94%. The trefoil/wheat treatment was rated at 50% suggesting fair yield potential. The soybean/trefoil treatment was the lowest rated birdsfoot trefoil treatment with a rating of 25% indicating poor yield potential. The red clover treatments appear to have good clover seed yield potential in all treatments with a high stand rating of 96% in the wheat/red clover treatment and a low rating of 80% in the soybean/red clover treatment.

The primary factor in the selection of a crop rotation will be the potential profitability of the rotation. Included in the results is an analysis of market value of grain and seed produced by each of the evaluated rotations from the first experiment based market prices in November of 2000 (Appendix, Result 1,Table 12). The grain yield of the continuous wheat rotation was valued at

$307 per acre; the most productive annual rotation was the soybean/wheat rotation, $352 per acre. Several of the annual/perennial rotations were determined to be more profitable than continuous wheat or the soybean/wheat rotation. In the first experiment the most profitable rotations were those with perennial ryegrass as the second season crop. Soybean/ryegrass, wheat/ryegrass, and flax/ryegrass rotations were valued at $456, $447, and $378 per acre respectively. The soybean/red clover, flax/trefoil, and the wheat/ trefoil rotation valued at $394, $357, and $354 per acre, respectively, were also more profitable than evaluated annual crop rotations.

Weed control: Weed control options are always a major consideration when selecting a new production system. Therefore, interseed combinations were selected that would permit chemical weed management. Weed control results for evaluated weed management programs are presented in Table 9. Evaluated chemical weed management programs were reasonably effective on the ambient weed population with some exceptions. Lambsquarter and to a lesser extent pigweed were problematic in some of the management programs. Imazethapyr, used for soybean/red clover and pure stand red clover treatments effectively suppressed all weed species present with the exception of lambsquarter. Post-emerge applied herbicides with better activity on lambsquarter that are compatible in soybean/red clover interseeding systems need to be identified. Some regrowth of pigweed and lambsquarter occurred following bentazon/quizalopfop application used in soybean/ryegrass and pure stand ryegrass treatments. Post-emerge glyphosate applications provided good control of the ambient weed population. Bromoxynil/fenoxaprop and bromoxynil/quizalofop applications were somewhat less effective on pigweed than on other weeds. This could be a problem in locations where pigweed densities are high. The level of suppression of pigweed by bromoxynil did seem to be adequate in wheat, but might be unsatisfactory in less competitive crop combinations such as those including flax. Grass weed control was found to be satisfactory with all evaluated herbicide combinations.

Soil moisture effects: In 1999 and in 2000 treatment differences in available soil moisture were not observed. However, it should be noted that rainfall amounts at the Roseau site were abnormally high, with both 1999 and 2000 in the 99th percentile of rainfall (MES Climatology Office data). Competition for soil moisture has been observed between interseeded crops at other sites, and should be a consideration in the selection of an intercrop rotation. Research continues in this area, observations in years with more typical rainfall are needed to establish crop/intercrop interactions with respect to soil moisture.

In ongoing research, canola/forage interseed rotations have been added to wheat/forage, flax/forage and soybean/forage rotations. Studies will be completed in late summer of 2002.

Objective 2. Evaluation of Perennial Legume Cover System for Small Grain Production.
In 1999, a two-year study was initiated at Morris, Crookston and Roseau, MN. Using a Latin Square experimental design, the hard red spring wheat (*Triticum aestivum*) cultivar 'Hamer', rated as susceptible to Fusarium head blight, was either intercropped with alfalfa (*Medicago sativa*), hairy vetch (*Vicia villosa*) or red clover (*Trifolium pratense*) or planted in monoculture and replicated four times at each location. The seeding rates and desired stands are listed in Appendix, Result 1,Table 1. The wheat was planted using a double-disk grain drill at all three locations. In Morris the legumes were planted with the grain drill when planting the wheat using a grass seed attachment. At the other two locations, the legumes were spread and raked in by hand prior to planting the wheat.

To control both grasses and broadleaf weeds trifluralin (Treflan) at 0.75lbs AI $acre^{-1}$ was applied pre-plant and incorporated in the seedbed. Additional broadleaf weed control was provided with one application of bromoxynil (Buctril) at 0.25 lbs AI $acre^{-1}$ once the legumes had reached the second trifoliate. At the Crookston location scab infected corn seed was used to provide a source of inoculum for *Fusarium graminearum.* In addition a misting system was used to promote disease development. No additional inoculum was applied to plots in Morris or Roseau.

The data collected included stand counts for both wheat and the legume at the 2 to 3 leaf stage of the spring wheat and again before grain harvest. In addition, plant height of the spring wheat and the legumes were measured just before grain harvest. Field severity of Fusarium head blight was estimated by multiplying incidence and severity estimates on a plot mean basis approximately 21 days after anthesis. A percent visually scab damaged kernels or VSK score was taken at harvest on a representative grain sample. Grain yield, test weight, and grain protein were determined for wheat by harvesting the center 5 feet of each plot. Biomass production of the legumes was estimated at grain harvest and a second time in late fall by hand cutting a one square yard subplot within each plot.

In 1999 plots in Roseau sustained heavy rains and the fourth replication was lost due to flooding. Similarly, the experiment in Crookston in 1999 was lost after the initial stand counts were taken. In 2000, the plots in Morris and Crookston suffered drought stress early in the season and continued drought in Morris during anthesis and grain fill resulted in no disease pressure. Analysis of variance was calculated by only using replications instead of the rows and columns used in the Latin Square design. All sources of variation, except the treatments were considered random. Differences amongst treatments were tested with the appropriate F-test. Least significant differences were calculated if treatments differed statistically.

The average initial stands of wheat and the legumes as well as the stands just prior to harvest are summarized in Appendix, Result 1,Table 3. Plant height of the wheat and the legumes are summarized in Table 3. No significant difference was found between treatments for the initial stand and the stand at harvest of wheat, indicating that the legumes did not influence early wheat development. No significant difference was observed for plant height of the wheat between the treatments. Hairy vetch was significantly taller then either alfalfa or clover and approached the top of the wheat canopy at harvest (Table 3). This posed a problem when combining the wheat. For this reason, hairy vetch is not a good candidate for intercropping with spring wheat.

Result 2. Cover crops for southern Minnesota

LCMR Budget:	$177,000.00
Balance:	$ 1,973.02

In-kind match of $65,000

I. REDUCING NITRATE LOSSES WITH A SCAVENGER CROP

Objective 1. Reducing the loss of nitrate-N from subsurface tile drainage.

Nitrate contamination impairs surface and ground water quality. Surface water is affected in areas where surface and ground waters are hydrologically connected, and this is especially the case were artificial drainage is necessary for crop production. An experiment was initiated in 1998 to determine whether a fall-seeded winter rye cover crop following corn might be an option for controlling nitrate-nitrogen losses through subsurface drainage in a corn-soybean sequence. Nitrogen was applied in spring as urea at a rate between 120 and 150 lbs N/acre. This experiment was conducted in southwest Minnesota on a Webster clay loam soil. The cover crop was planted annually in the fall following corn from the period 1998 to 2000. Considerable variation in climatic conditions from year-to-year during the project resulted in uneven water flow and nitrate-nitrogen losses from subsurface tile discharge. Variation in environmental conditions also impacted rye biomass, and residual soil nitrate levels. Detailed data is provided in Appendix, Result 2, Figures 1-3.

The first rye cover crop was planted in the fall of 1998 following corn harvest. Weather conditions during the fall of 1998 and spring of 1999 resulted in optimum growth of the fall seeded winter rye. In contrast, the fall of 1999 and spring of 2000 were warmer and drier than normal and the fall of 2000 and spring of 2001 that were cooler and wetter than normal. Both of these later weather conditions resulted in limited rye growth.

In 1999, tile flow and nitrate-nitrogen losses were greatest from plots in the corn-soybean sequence. Tile flow was reduced by 23% and nitrate-nitrogen losses were reduced by 50% for plots in the corn (rye)-soybean sequence in 1999. Unusually dry conditions in 2000 affected tile flow and nitrate-nitrogen losses for both crop sequences. Tile flow from plots averaged 0.01 acre-inches (range: 0.0 – 0.07 acre-inches) in 2000 compared with 6.5 acre-inches in 1999. Nitrate loss from the plots averaged 0.09 lbs N/acre (range: 0.0 – 0.5 lbs N/acre) compared with 21.6 lbs N/acre in 1999. Tile flow was reduced by 139% (from 0.036 to < 0.001 acre-inches) and nitrate loss was reduced by 101% (from 0.335 to 0.003 lbs N/acre) for plots in the corn(rye)-soybean sequence in 2000. Extraordinarily wet conditions in 2001 produced the greatest tile flow and nitrate-nitrogen losses from plots in the corn soybean sequence. Tile flow was reduced by 24% and nitrate-nitrogen losses were reduced by 24% for plots in the corn (rye)-soybean sequence in 2001. Tile flow from corn plots in the corn-soybean sequence averaged 19.7 acre-inches (range: 13.9 to 26.5 acre-inches) compared with flow from corn plots in the corn(rye)-soybean sequence that averaged 14.9 acre-inches (range: 11.7 to 17.4 acre-inches). Nitrate-nitrogen losses from corn plots in the corn-soybean sequence averaged 25.8 lbs N/acre (range: 21.5 to 32.5 lbs N/acre) compared with losses from corn plots in the corn(rye)-soybean sequence that averaged 19.7 lbs N/acres (range: 18.0 to 21.3 lbs N/acre).

Soil profile nitrate-nitrogen was measured to a five foot depth in the fall following harvest and in the spring before winter rye growth was terminated. Nitrate-nitrogen in the soil profile from plots in the corn(rye)-soybean sequence was significantly reduced between fall 1998 and spring 1999. Reductions in soil profile nitrate-nitrogen in these plots was attributed to nitrogen uptake by the growing rye. Dry conditions and poor rye growth between fall 1999 and spring 2000 resulted in minimal changes in soil profile nitrate nitrogen. Soil profile nitrate-nitrogen values increased sharply from spring 2000 to the fall 2000. The sharp increase was attributed to optimal conditions during 2000 for nitrogen mineralization from organic matter. Wet conditions and poor rye growth between fall 2000 and spring 2001 resulted in notable changes in soil profile nitrate nitrogen for the spring of 2001. Both cropping sequences showed dramatic losses in soil profile nitrate-nitrogen during the spring of 2001. These decreases were attributed in large part to nitrate-nitrogen leaching and to a lesser degree uptake of nitrogen by the growing rye.

Rye biomass was greatest in spring of 1999. Environmental conditions during 2000 and 2001 resulted in less than optimal rye growth. Soybean grain yield for 1999 and 2000 were unaffected by the presence of the rye cover crop.

These results suggest that cover cropping is beneficial to reducing tile flow and nitrate-nitrogen losses from subsurface drainage in a corn-soybean sequence. This results of this research indicate that the addition of a scavenger crop such as winter rye have the potential to be environmentally advantageous. Additional research is necessary to examine the economic and agronomic advantages and disadvantages of including a scavenger crop in the corn-soybean sequence. In addition, research to identify geographically sensitive areas where this practice would be most beneficial is warranted.

Objective 2. To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment I. Alternative crops seeded into corn

Experiments were established at the SWROC and on four farms near Lamberton, MN, to evaluate four cover crop species as potential scavenger crops for potentially leachable nitrogen within the corn phase of the corn-soybean rotation. The cover crops, which included annual ryegrass, mammoth red clover, oat, and winter rye, were interseeded into standing corn after second cultivation, at tasseling, or near physiological maturity. Additionally, the cover crops were planted at summit, linear slope, and foot slope landscape positions. Slopes at the experimental sites ranged from 5 to 10% (Appendix, Result 2, Objective 2, Table 1).

While annual ryegrass and red clover interseeded after second cultivation and annual ryegrass interseeded at corn tasseling emerged and established, oat and winter rye seedings at corn tasseling failed to emerge. Oat and rye seedings redone near physiological maturity of the corn did emerge and establish (For planting dates of the treatments, see the Appendix, Result 2, Table 2).

With the exception of red clover interseeding at one site (Appendix, Result 2, Objective 2, Table 3), cover crop interseeding did not reduce corn yield in these experiments. However, at two of the sites, corn yield at the foot slope was significantly higher than at the crest and linear slope landscape positions (Appendix, Result 2, Objective 2, Table 4).

Fall aboveground dry matter accumulation of the cover crop interseed treatments after corn harvest showed several trends across experimental sites: 1) annual ryegrass planted after second cultivation accumulated more biomass than the other interseed/planting date treatments, 2) drymatter accumulation of both the early and late ryegrass treatments and the winter rye treatment were generally higher at the foot slope position than at the summit and linear slope positions, and 3) the oat treatment, which had the lowest biomass accumulation of the cover crop treatments at four of the five sites, appeared unaffected by landscape position (Appendix, Result 2, Objective 2, Table 5). The effect of landscape position on red clover biomass accumulation varied from site to site. However, fall biomass accumulation of the cover crops was low; for example, the highest winter rye biomass accumulation in these trials (0.1 Mg ha^{-1}) was less than half that attained in previous experimentation with rye interseeding in corn in Minnesota.

Fall soil sampling to 1.2 m depth in the foot slopes of the experimental sites showed no significant differences between interseed treatments and the no-cover-crop control treatment in terms of nitrate-N in the soil profile, indicating that cover crop treatments in these experiments were not effective in scavenging potentially leachable nitrogen from the corn cropping system (Appendix, Result 2, Objective 2, Figure 1).

Spring aboveground biomass sampling of the overwintering interseed treatments, red clover and winter rye, showed no consistent trends across sites (Appendix, Result 2, Objective 2, Table 6). However, biomass accumulation at all sites was again low in comparison to biomass data of interseeds relayed into standing corn in previous experiments in Minnesota and the New York.

The results of soil profile analysis in these experiments suggest the interseed/planting date treatments in these trials did not effectively scavenge potentially leachable nitrogen from the corn cropping system. However, the growth of the cover crops (as indicated by the fall and spring biomass accumulation data)—and hence the ability of these crops to take up and sequester nitrogen—was probably affected by the unusual weather experienced by the southwest Minnesota region in fall 2000. The abnormally droughty conditions in early fall may have been a major factor in the poor performance of the cover crop treatments as scavengers of nitrogen. Experimentation with the most promising cover crop treatments is on-going in both corn and soybean crops at various sites in Minnesota. Please see the Appendix, Result 2, Objective 2, for presentation of data.

Experiment II. Cereal rye cover crop variety evaluation.

In the fall of 2000, five cereal rye varieties were planted in replicated trials at five locations across Minnesota in order to assess their early-season biomass production in a cropping system utilizing fall-planted rye as a cover-crop, principally following corn in a corn-soybean rotation. The five locations were Roseau, Morris, Lamberton, Waseca, and St. Paul. The five rye varieties included Rymin, Dakota, Dacold, Homil21, and Homil22. Rymin has been grown in Minnesota since the mid-1970s, where the other varieties were newer releases from North Dakota and Canada. Two varieties (Homil21 and Homil22) had never been grown in Minnesota, but were reported to be substantially greater in early-season biomass production. They were developed in

Canada initially for their forage potential in a rice-rye cropping system utilized in Korea.

Agronomic management practices from each of the five locations are listed in Appendix, Result 2, Objective 2, Experiment II, Table 1. Good stand establishment occurred at all five locations, however, date of planting and previous cropping history had a big influence on rye growth and development in the fall prior to winter freeze-up. The earliest planted locations (Roseau and St. Paul) had substantially more biomass production than the later planted locations. The St. Paul location was planted into a field with has had a history of heavy manure applications where had corn silage had been removed just prior to rye planting. At the other four locations, the previous crop residue remained in the field. In the spring just after snow melt, rye at St. Paul averaged 1.6 times the biomass as that at Roseau and 5 times the biomass as that at Lamberton (Appendix, Result 2, Objective 2, Experiment II, Table 2). Differences in biomass and N uptake in the aboveground plant tissue between the five rye varieties were evident by snow melt in the spring. Based on tissue analysis data in late-March and early-April from three locations, Homil21 had more biomass and N uptake than Rymin.

The differences in aboveground biomass and N uptake between the rye varieties was evident at all locations in early May, when the rye cover crop would typically be managed (killed) for subsequent soybean planting (Appendix, Result 2, Objective 2, Experiment II, Table 3). At that time, the rye at the Morris location, which was planted the latest in the previous fall, averaged the least biomass and N uptake. The rye averaged the most biomass at St. Paul, which was slightly more than two times the biomass observed at Roseau, the location with the second highest early May biomass production.

In early May, there were differences between the varieties in biomass, N uptake, and N percentage in aboveground tissue (Appendix, Result 2, Objective 2, Experiment II, Table 3). No variety yielded more above ground biomass or had more N uptake than Homil21 at any of the five locations. At four of the five locations Homil21 had more aboveground biomass than Rymin, and at two of the five locations Homil21 had more N uptake than Rymin. Averaged over all locations, the yield of Rymin was only 75% of the yield and had only 78% of the N uptake compared with Homil21. The Homil21 began jointing before Rymin, and at St. Paul was approximately 1 inch taller in early May (14 vs. 13 inches, respectively). At St. Paul, there was dieback of approximately 25% of the plants for two varieties, Rymin and Homil 22 due to pink snow mold (*Fusarium microdochium* or *F. nivale*).

Figure 1 (Appendix, Result 2, Objective 2, Experiment II,) shows aboveground biomass accumulation and N uptake Rymin and Homil21 at St. Paul over time. Note the explosive growth and N uptake of the varieties in late-April and early-May. The spring of 2001 was relatively late in terms of snow melt and early season heat units. It is speculated that in a more normal year, the explosive growth and N uptake would have been observed one to two weeks earlier.

These preliminary data suggest there are rye varieties which may be better suited as a cover crop in terms of early-season biomass production and N uptake compared with Rymin, the variety most commonly grown in Minnesota.

II. EVALUATING LEGUMES INTERCROPPED IN SMALL GRAINS

Experiments designed to evaluate forage legume species as underseeds in small grain crops were conducted from 1999-2001 at the Southwest Research and Outreach Center (SWROC) in Lamberton, MN, and from 2000-2001 at four farms in southwestern and west central Minnesota. Detailed data is provided in Appendix, Result 2-II Tables 1-13.. At the SWROC and three of the farms, the experiments were conducted under organic management. The 1999 SWROC experiment included two small grain species (wheat and oat), two preplant tillage regimes (no-till and disk-till), and five legume species: a non-dormant alfalfa variety, mammoth red clover, yellow sweetclover, berseem clover, and an annual medic (cultivar and seeding rates are shown in Table 1). The tillage treatment was included to test farmer observations that no-till planting enhances small grain and legume establishment and reduces weed interference. A subplot treatment without an interseeded legume was also included to assess the effect of legume presence on small grain performance. In 2000, the original experiment was planted to corn to observe legume underseed effects on a subsequent crop, and the small grain/legume underseed experiment was repeated with a slightly altered experimental design (Table 2) on a new site. Because farmer cooperators were allowed to stipulate the small grain a legume treatments to be evaluated, treatments varied between on-farm sites. Two farm experiments evaluated alfalfa, red clover, yellow sweetclover, and no interseed treatments in barley. In the other two experiments, farmer cooperators compared their standard underseed species to berseem clover and annual medic. Farmer cooperators and the treatment structure on each farm are listed in Table 3.

In the SWROC experiments, legume underseed performance varied with experimental year. In the 1999 experiment, mammoth red clover and alfalfa produced the greatest aboveground drymatter accumulation at both small grain harvest and at fall sampling Table 4). However, in even the best performing treatments, legume dry matter accumulation was poor (<0.8 Mg ha^{-1}), probably as a result of low rainfall and insect attack. In 2000, legume dry matter accumulation was somewhat higher at small grain harvest: the yellow sweetclover treatment accumulated the greatest amount (1.16 Mg ha^{-1}) with a total N accumulation in aboveground tissue of 32 kg ha^{-1} Table 5). Reduced rainfall in late summer and fall appeared to limit legume biomass accumulation by fall sampling: the highest dry matter accumulation (0.45 Mg ha^{-1}) was in the red clover treatment (Appendix, Table 5). In both years, the berseem clover and annual medic treatments established poorly and accumulated negligible aboveground dry matter (<0.07 Mg ha^{-1}). Tillage and small grain crop treatments had no effect on legume performance in either year. In both the on-farm experiments comparing alfalfa, red clover, and yellow sweetclover, yellow sweetclover produced the most legume biomass by small grain harvest; N accumulation in sweetclover biomass by small grain harvest was 70 kg ha^{-1} at one farm and 34 kg ha^{-1} at the other farm (Appendix, Table 6). Biomass accumulation at fall sampling was equivalent between the three legume treatments at one site and highest in the yellow sweetclover and alfalfa treatments at the other site Table 7). In the other two on-farm experiments, the farmers' standard underseed species, 'nitro+' alfalfa at one site and a mammoth red clover/yellow sweetclover mixture at the other site, had significantly higher biomass accumulations at both small grain harvest and fall sampling than did annual medic and berseem clover treatments (Tables 6-7). N accumulation in legume aboveground dry matter was 37 and 14 kg ha^{-1} in the red clover/sweetclover and alfalfa treatments, respectively (Table 6).

Biomass accumulation of broadleaf and grass weeds was not significantly reduced by legume treatments in comparison to a control treatment of no legume underseed in either of the SWROC experiments or in the on-farm trials (see, e.g., Table 8). In the 1999 SWROC experiment, dry weight accumulation of broadleaf weeds was consistently greater in the disked treatments than in no-till treatments, with the exception of red clover plots (Table 9). In the 2000 SWROC experiment, both grass and broadleaf weed biomass accumulation at small grain harvest was significantly greater in oat than wheat plots (Table 10), a probable result of the poor establishment and growth of the oat crop (see below).

In the 1999 SWROC experiment, while wheat yield was unaffected by legume treatment, oat yield was reduced by 13% in the presence of legume underseeds as compared to the no underseed control (Table 11). In 2000, in both the SWROC and on-farm experiments, small grain yield in the legume treatments did not differ significantly from that in control treatments of no legume underseed (see, e.g.,Table 12). However, a trend across farms indicated that yield tended to be highest in the legume-free treatments. In the 2000 SWROC experiment, oat and wheat yields were differentially affected by tillage treatment: Wheat yield varied by 5% between the no-till and disk-till treatments, while oat yield was 36% lower in the no-till than the disk till treatment (Table 13). The negative effect of the no-till treatment on oat yield in this experiment may have been caused by the combination of poor oat establishment (the oat stand count was 120 plant m^{-2} – substantially less than 215 plants m^{-2} considered necessary for adequate oat grain yield) and interference by Canada thistle, the major broadleaf weed species in the 2000 SWROC experiment. Emergence and growth of Canada thistle, a perennial species, are likely to be favored in undisturbed soil conditions in crop plant population is low.

Corn yield following the 1999 SWROC experiment was unaffected by tillage, small grain, or legume treatments (data not shown). The lack of legume effects is a likely result of the poor performance of the legume underseeds the previous year. In 2001, corn has been planted in the 2000 SWROC experimental site and at two of the four on-farm sites. Corn yield data and N accumulation data will be gathered from these sites and an economic analysis of legume underseed treatments developed.

Results from these experiments to date suggest that yellow sweetclover, mammoth red clover, and 'nitro+' alfalfa have the potential to produce significant biomass and N accumulation as underseeds in a small grain crop. Small grain yield data suggests that there is a risk of slight to moderate yield loss due to the presence of legume underseeds. Legume underseeds were not effective at reducing weed biomass accumulation in small grains. Preplant tillage options did not have consistent effects on weeds or small grain yield. The practice of underseeding legumes in small grains would appear to have potential benefits both in terms of reducing fertilizer inputs and increasing crop diversity in both conventional and organic management systems.

III. Kura Clover Living Mulch System

Experiments to evaluated Kura clover as a living mulch for corn and soybean production were conducted at Rosemount and Becker, MN in 2000 and corn yields resulting from treatment application were provided in the December 2000 report. In June of 2001, we measured yields and stand density of Kura Clover that regrew following the corn harvest in fall of 2001. Kura clover yields were similar among the treatments and averaged 0.7 and 1.2 ton/acre for the fall-spring combination and spring disk treatments, respectively, averaged for the two locations. Yields were lower at Becker than Rosemount. As expected those treatments that resulted in greater suppression in 2000 also produced the least yield in spring 2001. These yields are comparable to those of an established stand. A complete set of information is shown in Appendix, Result 2, Table l-2) and described in the draft version of a fact sheet on Kura clover Living Mulch (see Appendix).

An economic analysis was conducted on results from the 2000 trial. Overall, returns were greatest for the treatments that resulted in the greatest grain yields. Spring disking, only minimally suppressed the Kura clover and consequently resulted in the lower corn grain yield than the fall and spring combination tillage. Consequently, net returns were also lower for the spring disking treatment. Within the fall chisel plow-spring disk treatment, highest net returns were received with Rhizo Kura clover receiving no N fertilization. In other words, we saw no consistent effect of fertilization with 150 lb/acre on corn yields. To clarify this effect, we took soil samples from a 2001 version of the 2000 trial at both locations. The 2001 trial was seeded in May and soil sampled in early June. Detailed results of soil sampling are shown in Appendix. Corn grain yield will be measured in the fall. Our observations for 2001 are that the combination of the wet cool spring that delayed planting and the hot dry summer have enhanced competition between the Kura clover and corn.

Soil nitrate-nitrogen (NO_3-N) values generally reflect a high level of soil N at both sites (Table 3). The in-season soil NO_3-N data indicates that mineralization of N from Kura clover and birdsfoot trefoil was present and significant depending on location. The levels were generally lower at Becker because of the lower inherent soil organic matter level and decreased with depth in the root zone. There was little variation in soil N due to previous legume treatment effects. The effectiveness of the Kura clover living mulch system is summarized in the attached fact sheet. Under normal growing conditions it is possible to use the living mulch system provided that a high level of suppression occurs. With abnormal conditions that discourage corn growth, competition with Kura clover can greatly reduce corn yield consequently this strategy requires a high level of management by producers.

Result 3. Agroforestry

LCMR Budget: $65,000.00
Balance: $23,474.05

In-kind match of $5,000

The primary reason for the large budget balance is that we utilized part-time technical labor to complete the research. In addition, we did not spend the total funds available for plant materials/supplies or for contracts with cooperators.

Objective 1: Evaluation of hazelnut varieties

In trials at Staples, Jackson, and Rosemount, MN there were no consistent and significant differences among varieties or between native and hybrid hazelnuts in terms of winter survival. Detailed data presented in Appendix, Result 3.

Objective 2: Evaluation of management practices on hazelnuts

Large field plots in Staples, Montevideo, Morris, and Jackson MN were evaluated for winter survival. The establishment treatments showed an effect on hazelnut seedling winter survival. All sites were evaluated by measuring plant mortality, plant height, number of branches, number of ground shoots and presence and degree of damage from herbivores or disease. Treatment effects on hazelnut survival over the winter of 2000-2001 were in some cases large and in others insignificant. Detailed data is provided in Appendix, Result 3.

At Morris, plant losses over the winter were about fifty percent as great when hazelnuts were mulched with landscape mát (-38.2%) as when mulched with wool (-27%) and much greater than when not mulched at all (+2.6%). These differences were determined to be statistically significant. For landscape mat, the losses were due to rodents living under the mat. In the case of the wool mulch, weeds sprouting under the mat easily lifted the material. Consequently, the mat became subject to winds and smothered the hazelnut seedlings and then blew over them. In the cultivation trial plants that were counted as dead in 2000 sprouted back in the spring of 2001.

At Jackson, MN there was no statistically significant difference in seedling mortality overall from planting to spring of 2001. This may be due to the fact that field technicians placed wood chips on top of the fabric after noticing that the hazelnut leaves were suffering from heat stress. Losses over the winter were significant. The wood mulch treatment had a winter mortality rate of 20.8% while the landscape fabric had a mortality rate of 10.3%. Also, the number of branches and sprouts was determined to be significantly different between treatments. It was noted that the holes cut in the landscape fabric were very small and therefore there was little space for new sprouts to emerge.

At the Staples site, the winter mortality of the plots cultivated without mulch (3.5%) was significantly higher than the plot without mulch (0.7%). The windbreak site actually saw a decrease in mortality from fall of 2000 (13.7%) to spring of 2001 (8.3%). Apparently, plants that had been devastated by herbivores in the fall sprouted back in the spring.

At the Gibson site near Montevideo winter mortality accounted for about 7% of total losses since planting. It is not clear what caused this mortality.

At the Rosemount site where weeds were controlled by manual weeding, very little winter mortality occurred and stands were not affected by K fertility treatment.

On-farm evaluation of hazelnuts designed to sample diverse environments was conducted at farms clustered in north central, west central, and southwest, MN. On these sites, survival of seedlings ranged from 10 to 47% although heights of surviving plants was similar. The low survivability of only 47% at some farms reflects the challenges of controlling factors influencing establishment: control of competing vegetation; providing adequate moisture, and protecting seedlings against predators.

Follow-up care and maintenance of the sites was accomplished as of June 28, 2001 for the large field plots in Staples, Montevideo, Morris, and Jackson MN field station sites and a number of the smaller farm sites.

A fact sheet was developed to succinctly share the information generated from this study (see Appendix). In summary, hybrid hazelnuts will establish and overwinter in much of Minnesota; however, suppression of vegetation during the seeding year and control of rodents and other predators is advised.

Result 4. Indigenous native perennial legumes

LCMR Budget: $116,000.00
Balance: $ 5,346.46

In-Kind match of $30,000

Unspent balance due to a slight reduction in labor needs

Objective 1:

Establishment trials were initiated at Montevideo and Milan in 1999. On-farm plot areas were identified and tested for soil fertility. Frost seeded plots were established in November, 1999 and spring seeded plots were established in April, 2000. Stand counts were taken in June, 2000 and 2001 at both on-farm sites (Appendix, Result 4, Table 1). At both sites, the establishment of false indigo and Illinois bundleflower was more successful with spring seedings than with frost seedings in the fall. Stand counts for the fall frost seeding showed no established plants of either species in June, 2000. The spring seeded plots showed that Illinois bundleflower established better than false indigo averaging 40 plants per square meter verses four plants per square meter for false indigo. However, the extremely dry conditions during the Fall, 2000 resulted in the complete loss of both legumes on the Handeen Farm and the loss of Illinois bundleflower on the Struxness Farm. Stand counts of False Indigo were reduced to one plant per square meter on the Struxness Farm. Stands were to poor to take dry matter yields of grasses, legumes and weeds and to determine the forage quality of the pasture.

Establishment trials were initiated at Lake City and Wilson in Spring, 2000. On-farm plot areas were identified and tested for soil fertility. Spring seeded plots were established in May or June, 2000. Stand counts were taken in September, 2000 and June, 2001 (Appendix, Result 4, Table 1). In September, 2000, the spring establishment trials in southeastern Minnesota initially showed better success with both species. Illinois bundleflower has greater plant counts than false indigo at all on-farm sites but did not establish when competition from other companion species was not controlled (Lake City location). In June, 2001, plant stand counts were reduced but were adequate at the Dansburger Farm. At the Lentz Farm, Illinois bundleflower and false indigo were completely lost in the unclipped treatment and were greatly reduced in the clipped treatment. Competition must be controlled in established pastures to have successful introduction of these legumes into pastures. Stands were inadequate to take dry matter yields of grasses, legumes and weeds and to determine the forage quality of the pasture.

Because of difficulties in establishment of these native legumes, determination of persistence under grazing was not possible

Objective 2:

Breeding programs for Illinois bundleflower and False indigo was initiated by establishing 20 populations of each species at Becker and St. Paul, MN. Basic genetic and agronomic information about false indigo and Illinois bundleflower for use in developing successful plant breeding strategies and agronomic research priorities was collected during 1999 and 2000. Analysis of the Illinois bundleflower data and False Indigo data is completed (Appendix, Result 4, Tables 2 and 3).

Three plant breeding populations of Illinois bundleflower were identified and are currently in seed increase for potential variety release of this native legume for grazing and restoration. Initial seed of the three populations will be harvested in September, 2001 for further evaluations. False indigo collections with excellent potential agronomic and forage quality traits have been identified from the 20 accessions evaluated for potential use in a future plant improvement program.

V. DISSEMINATION/EDUCATION:

In summary we conducted over 30 professional and public presentations of the results of this study. Total attendance exceeded 2000.

Report for 1 July 2001.

Result 1. Cover crops for northwestern Minnesota

- Betts, K. Legume cover crops. 2001. The Grass Seed Institute. Baudette, MN 80 attended.
- Wyse, D.L. Legume covers. 2001. The Magnusson Research Farm Field Day. Roseau, MN. 60 attended.

Result 2. Cover crops for southern Minnesota

Presentations at professional meetings:

- Porter, P.M. 2001. Rye cultivar evaluation for use as a cover crop in Minnesota. In Agronomy Abstracts. ASA-CSSA-SSSA, Madison, WI.

- Strock, J.S., M.P. Russelle, and P.M. Porter. 2001. Cover cropping and nitrate losses from subsurface drainage in a row crop system. *In* Fifth Int. Conf. on Diffuse/Non-point Source Pollution and Watershed Management. Conf. of Int. Water Association, Milwaukee, WI. June 10-14, 2001.

- Strock, J.S., M.P. Russelle, and P.M. Porter. 2001. Environmental variability and cover crop capacity for reducing nitrate losses from tile drainage. *In* Second Int. Nitrogen Conf. Conf. of Ecological Soc. Am., Potomac, MD. Oct. 14-18, 2001.

- Strock, J.S., M.P. Russelle, and P.M. Porter. 2001. Nitrate loss through subsurface drainage affected by climate and cover cropping. *In* Agronomy abstracts. ASA-CSSA-SSSA, Madison, WI.

Producer/public meetings.

- Dyck, E. Annual Meeting of Organic Growers and Buyers Association. 9 December 2000. Presentation of results of on-farm scavenger experiments and experiments on intercropping legumes in small grains. Red Wing, MN. 65 attended.

- Dyck, E. Workshop on small grains and alternative crops. 20 January 2001. Presentation of results of on-farm scavenger experiments and experiments on intercropping legumes in small grains by both researchers and cooperating farmers. Southwest Research and Outreach Center, Lamberton, MN. 53 attended.

- Dyck, E. Annual Meeting of the Northern Plains Sustainable Agriculture Society. 10 February 2001. Presentation of results of on-farm scavenger experiments and experiments on intercropping legumes in small grains. Aberdeen, SD. 90 attended.

- Dyck, E. On-farm scavenger experiments and experiments on intercropping legumes in small grains. 15 March 2001. Organic University, Midwest Organic and Sustainable Education Services. La Crosse, WI. 80 attended.

- Porter, P.M. 2001. Rye and other cover crops. . June 19, 2001. Summer Field Day. University of Minnesota Southern Research and Outreach Center. Waseca, MN. 100 attended.

- Porter, P.M. 2001. Fall-planted rye as a cover crop. July 19 and 20, 2001. Organic Production Workshops. Moorhead, MN and Fertile, MN. 40 attended.

Result 3. Agroforestry

Producer/public meetings

- Wymar, P. A Hazelnut workshop was held in Montevideo on March 29, 2001. Philip Rutter of Badgersett Research Corporation spoke about growth and yields of hazelnuts. Producers and members of nonprofit organizations including Land Stewardship Project and the Sustainable Farming Association were in attendance. 20 attended.

- A series of small group meetings were held by P. Wymar:

- On March 25, 2001 a meeting was held in Montevideo with 3 of the project participants discussing their experiences and lessons learned.

- Six farm sites were visited in April 2001 to check on hazel survival and get information from growers on factors influencing establishment..

- On May 14, 2001, a meeting was held with four station personnel at Staples Outreach Center to discuss continuation of the project and experimental plot management. The experiment station personnel and the Central MN participants had met separately in the fall to discuss the potential for continuing the project through the Central MN Regional Partnership.

Result 4. Indigenous native perennial legumes

Producer/public meetings

- Prairie Plant Field Day was held on September 7, 2000 at Wilson, MN to discuss establishment techniques for False Indigo and Illinois bundleflower in cooperation with the Land Stewardship Project in Lewiston, 15 farmers attended.

- Indigenous Legume Growers Winter Meetings was held on March 29, 2001 in Montevideo, MN to discuss the potential uses, establishment techniques, and potential management strategies on native legumes concentrating on Illinois bundleflower and false indigo in cooperation with Western Minnesota Land Stewardship Project, 20 producers attended.

- Ristau, E., N. Ehlke, C. Sheaffer, and D. Wyse. Native legume seed and plant program. Grass-legume Seed Institute. March 21, 2001. Grass-legume Seed Institute.Warroad, MN. 75 attended.

- Wyse, D. Setting the stage for native plant seed production. April 4, 2000. Grass-legume seed Institute, Baudette, MN. 80 attended.

- DeHaan, L.R., N.J. Ehlke, C.C. Sheaffer, and Wyse. 29 April 2000. , Indigenous Legumes for Minnesota Landscapes, Symposium paper presented at the Enhanced Landscape, Human and Animal Health Symposium, University of Minnesota. 75 scientists attended.

Popular producer publication:

- Dehaan, L., and P. Peterson. 2001. Illinois bundleflower: a legume for summer pastures? Minnesota Forage Update Vol. XXVI No.4.

Scientific publications:

- DeHaan, L.R., N.J. Ehlke, and C.C. Sheaffer. 2000. Analysis of diversity in northern populations of Illinois bundleflower. Agron. Abstr. American Society of Agronomy, Madison, WI. *In* Agronomy abstracts. ASA-CSSA-SSSA, Madison, WI.
  Two publications for scientific publication have been developed. These are attached in the appendix.

An Indigenous Legume web page has been developed (http://www.100megspop3.com/pil/) with educational information including information on the following:

- Inventory of indigenous legumes evaluated for economic potential with photographs, common names, and scientific names
- Inoculation and nitrogen fixation in native legumes
- Salt tolerance of native species
- Personnel involved in the project

VI. CONTEXT

A. Significance: Our current agricultural cropping systems contain less biological diversity than at any time in history. Loss of diversity has resulted from continual simplification of farm production leading to the present focus on production of a few crops over large acreage. It is increasingly clear that simplified farming is causing a crisis in rural Minnesota. This crisis is felt in rural communities that have lost population, businesses, churches, schools and social institutions as smaller diversified farms have been replaced by larger operations focused on a single commodity. The crisis is also felt by all citizens as our precious water resources are degraded by agricultural pollution. We provide two notable examples of this crisis situation: In the Red River Valley of Minnesota and North Dakota, a scab (*Fusarium* spp.) epidemic associated with short rotations containing wheat and barley monocultures has severely threatened the livelihood of rural communities in the Valley, depriving spring wheat producing region of $4.2 billion dollars of income since 1992.

In Southern Minnesota, farm diversity has declined in recent decades and about 70% of the land area is planted to corn and soybeans. This system has required high inputs of agrochemicals, including fertilizers and pesticides. The latter are required by dramatic proliferation of serious plant pests such as European corn borers, soybean cyst nematodes, root rots, and weeds. Movement of agrochemicals and soil into lakes and rivers throughout the region have seriously degraded extremely valuable water resources.

For the long-term viability of our society, a sustainable agriculture is essential. Many of the current crop production systems occupying our rural landscapes are not sustainable. These systems are now being challenged by increasing insect, disease, and weed problems; increased soil and water degradation; vulnerability to climate variability; and economic stress. To date, challenges to current systems have been met with increased inputs of costly technology or subsidies, which have often failed to be cost-effective and socially acceptable. Our concerted effort to promote diversification of Minnesota agriculture offers a promising alternative to these failed past approaches. We believe that this effort will provide an essential catalyst to a Minnesota agriculture that is sustainable in environmental, social, and economic terms. Our project will provide new information on the use of cover crops, agroforestry, and indigenous legumes for landscapes in diverse climates and soils in Minnesota.

B. Time: We are requesting funds for 1999-2001; however, we recognize that additional years of field research are needed to provide greater confidence in the results of experiments with annual plants and to adequately evaluate perennial species. Therefore, we intend to seek additional funding from LCMR or other sources to continue the research beyond 2001.

C. Budget Context: Our previous funding of cover crops research is limited to a $35,000 grant from SARE (1993) to evaluate its use as a smother crop in corn and soybean systems. This research provides the basis for this request using a diversity of smother crops in southern Minnesota.

1. BUDGET (2 year):

Personnel (paid from LCMR funds)

Non-profit organizations

- Audrey Arner (Land Stewardship Project, Montevideo) paid for 0.50 time on Indigenous Legumes ($34,000) for planning and supervision of field research.
- Richard Ness (Land Stewardship Project, Lewiston) paid for 0.25 time on Cover Crop research ($17,000) for planning and supervision of field research.
- DeEtta Bilek (Sustainable Farming Association) paid for 0.25 time on Southern Minnesota Cover Crops ($10,000) and 0.12 time on Northwest Minnesota Cover Crops ($4,000) for planning and supervision of on-farm research.

University of Minnesota (note: all positions are temporary)

- Technicians (Unknown; not hired; except where noted), for conducting field research to obtain objectives:
  One technician (0.50 time, at $30,000) to work on Indigenous Legumes.
  One technician (0.75 time; at $45,000) to work in Agroforestry.
  Two technicians (0.50 time; at $60,000 total) to work on Southern Minnesota Cover Crops.

- Research assistantship:
  One 0.50 time research assistantship for 2 years ($40,000).
  One 0.50 time student research assistantship ($40,000) for future student for 2 year participation in Southern Minnesota Cover Crop Projects.

- Student Internships:
  A total of $60,000 is provided to pay undergraduate student internships for work on the various projects.

Travel (all instate travel to conduct field research):

The University of Minnesota will spend the following for the various projects: $1,000 for Agroforestry; $4,000 for Northwest Cover Crops, $2,000 for Southern Minnesota Cover Crops. Cost rate $0.33 per mile.

Contracts:

University of Minnesota

- For payment for independent contractors: Phil Rutter for consulting on the Agroforestry project ($5,000).
- For payment of farmers for participation in Cover Crops Projects ($4,000). Farmers provide land, labor, and supervision of the project.

Supplies:

University of Minnesota

- For all projects, supply funds are used for purchase of seed or plant materials, fertilizer, and miscellaneous plot equipment (flags, stakes, harvest bags).
- For the Southern Minnesota Cover Crop Project, supply costs will include purchase of samplers for extracting leached water.
- For Agroforestry, supply costs will include purchase of plant material.

Sample Analysis:

University of Minnesota

For all projects, sample analysis will include costs for soil testing and testing of plant materials for elemental nutrient composition. For the Southern MN Cover Crops Project, costs for N analysis of soil water will be covered by the requested funds.

VII. COOPERATION: (LCMR dollars received and % time in bold)

A management team will administrate the project and coordinate activities. The management team will insure that there is significant linkage and cohesiveness among the components. The management team will consist of Craig Sheaffer (LCMR Project Manager), Paul Porter, and Nancy Ehlke. Each specific project will also develop a management team to insure efficient project operation.

Project 1: Cover Crops-Northwestern Minnesota

University of Minnesota:

Dr. Donald Wyse, University of Minnesota, Dept. of Agronomy and Plant Genetics

Dr. Jochum Wiersma, Northwest Experiment Station, Crookston, MN

Non-profits:

DeEtta Bilek, Program Manager for the MN Sustainable Farming Assoc., Aldrich **(0.12 time; $4,000)**

Producers:

Jaime DeRosier, Red Lake Falls, MN. Carmen Fernholz, Madison, MN

Project 2: Cover Crops-Southern Minnesota

Scientists (University of Minnesota)

Dr. Paul Porter, Assoc. Prof., U of MN, Southwest Experiment Station, Lamberton

Dr. Deborah L. Allan, Professor, U of MN, Dept of Soil, Water, and Climate, St. Paul

Dr. Elizabeth Dyck, Asst. Prof., U. of MN, Lamberton, and SW State Univ., Marshall

Dr. Nicholas Jordan, Assoc. Prof., U of MN, Department of Agronomy and Plant Genetics

Dr. Michael Russelle, Prof and Soil Scientist, USDA-ARS, St. Paul, MN

Dr. Craig Sheaffer, Professor, U of MN, Dept of Agronomy and Plant Genetics

Dr. Donald Wyse, Professor, U of MN, Dept of Agronomy and Plant Genetics.

Non-profits:

Mr. Richard Ness, Coordinator of the Farm Beginnings Program and Monitoring Program, Land Stewardship Project, Lewiston. **(0.25 time; $17,000)**

DeEtta Bilek, Program Manager for the MN Sustainable Farming Assoc. Aldrich. **(0.25 time; $10,000)**

Producers:

Eldon Mitzner, Tracy in Lyon County

Don DeWeerd, Pipestone, Pipestone County

Carmen Fernholtz, Madison, Lac Qui Parle County

Larry Olson, Montevideo, Chippewa County

Project 3. Agroforestry

Scientists:

Craig Sheaffer, Department of Agronomy, University of Minnesota

Jim Luby, Professor, Department of Horticulture, University of Minnesota, St. Paul

Paul Wymar Watershed Technician Chippewa River Watershed Project 629 N 11th Street Montevideo, MN 56265

Consultants: Philip Rutter, Proprietor, Badgersett Research Farm, Badgersett, MN

Producer: Dennis Gibson, Montevideo, MN; Richard Handeen, Montevideo

Project 4. Indigenous Legumes

Scientists:

Dr. Nancy Ehlke, Professor, U of MN, Dept. of Agronomy and Plant Genetics

Dr. Greg Cuomo, Assistant Professor, U of MN, West Central Experiment Station

Mr. Lee De Haan, Research Assistant, U of MN, Dept. of Agronomy and Plant Genetics **(0.50 time; $40,000)**

Dr. Craig Sheaffer, Professor, U of MN, Dept. of Agronomy and Plant Genetics

Non-profits:

Audrey Arner, Western Minnesota Office of the Land Stewardship Project, Montevideo. **(0.50 time, $34,000)**

Producers:

Jodi Dansingburg, Rushford; Richard Handeen, Montevideo;

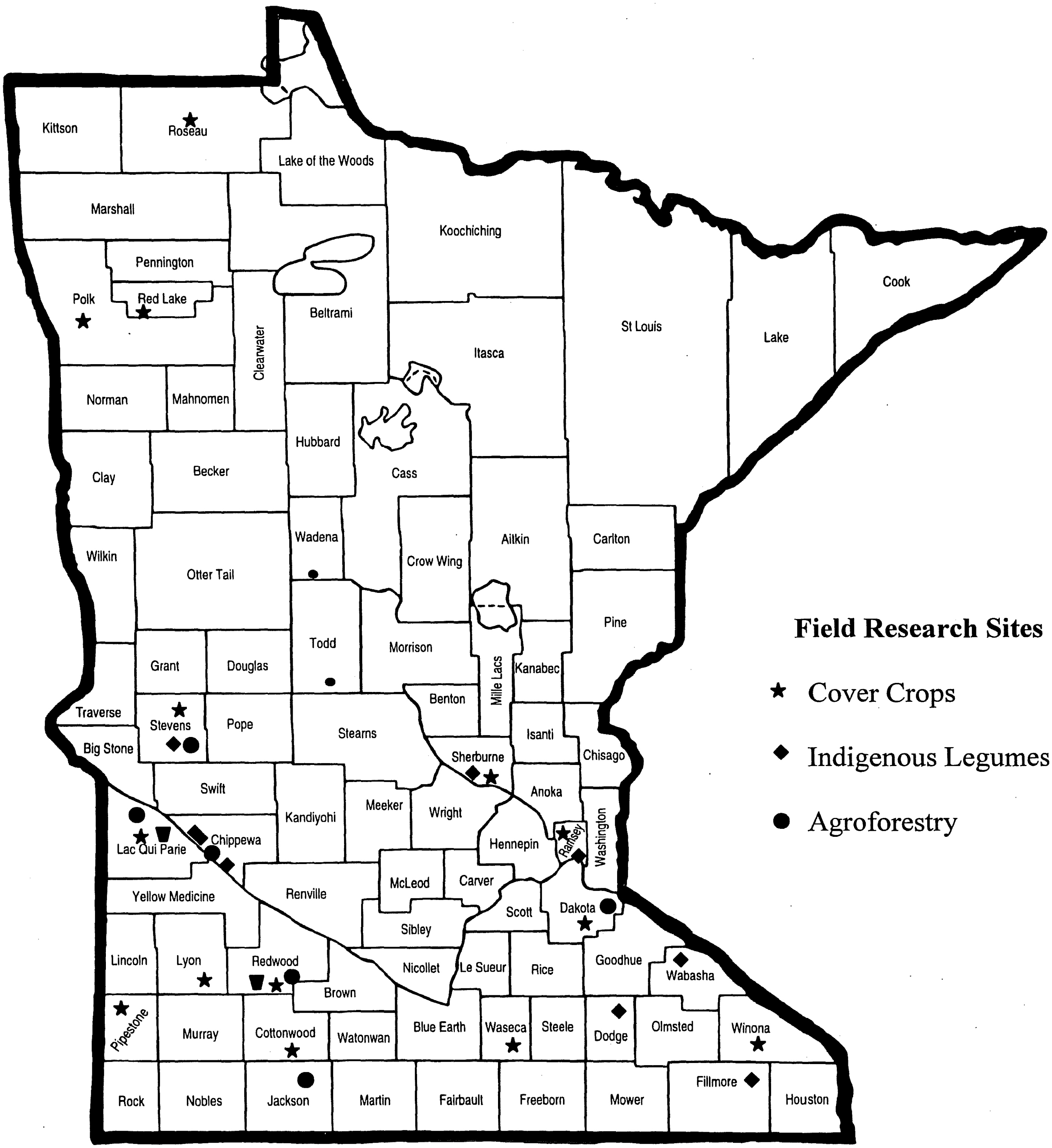
Don Struxness, Milan.

VIII. LOCATIONS: (see attached map)

1. **Project: Cover Crops-Northwestern Minnesota**
   Northwest Experiment Station, Crookston, Polk County
   On-farm sites: Red Lake Falls, Red Lake County; Crookston, Polk County; Roseau, Roseau County; Madison, Lac Qui Parle County

2. **Project: Cover Crops-Southern Minnesota**
   Southwest Experiment Station, Lamberton, Redwood County
   Rosemount Experiment Station, Rosemount, Dakota County
   Sand Plain Experiment Station, Becker, Sherburne County
   Southern Experiment Station, Waseca, Waseca County
   St. Paul Campus, Ramsey County
   On-farm sites: Lamberton, Redwood County; Madison, Lac Qui Parle County, Tracy, Lyon County; Sanborn, Redwood County; Pipestone, Pipestone County.
3. **Projects: Agroforestry**
   Staples Irrigation Center, Staples, Wadena County
   Southwest Experiment Station, Lamberton, Redwood County
   West Central Experiment Station, Morris, Stevens County
   Rosemount Experiment Station, Rosemount, Dakota
   On-farm sites: Chippewa, Todd, LacQuiParie, Jackson Counties;.
4. **Project: Indigenous Legumes**
   West Central Experiment Station, Morris, Stevens County.
   Sand Plain Experiment Station, Becker, Sherburne county
   St. Paul Campus, Ramsey County
   On-farm sites: Rushford, Fillmore County; Montevideo, Chippewa County; Milan, Chippewa County; Lake City, Wabasha Count

LCMR Proposal 1999
Title: Diversifying Agriculture for Environmental, Economic, and Social Benefits
Project Manager: Craig Sheaffer
Affiliation: Department of Agronomy and Plant Genetics, University of Minnesota
Mailing Address: 411 Borlaug Hall, 1991 U. Buford Circle, St. Paul, MN 55108
Telephone: 612-625-7224 **Email:** sheaf001@maroon.tc.umn.edu **Fax:** 612-625-1268
Total Biennial Project Budget LCMR: $400,000



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Research for diversification. Two-year budget breakdown by product.

Category	Organization [a]	Northwest Minnesota Cover Crops	Southern Minnesota Cover Crops	Agro-forestry	Indigenous Legumes	Total	Category Total
		$					
Personnel: [b]							
Student Intern	U of MN	12,000	14,000	7,000	12,000	45,000	
Technician	U of MN	15,000	60,000	43,000	30,000	148.000	
Staff	SFA	4,000	10,000			28,000	
Staff	LSP		17,000	0	34,000	68,000	
Research Assistantship	U of MN	0	42,500	0	42,500	42,500	331,500
Travel [c]	U of MN	4,000	4,000	3,000	0	11,000	11,000
Contracts: [d]							
Professional	U of MN			5,000		10,000	
Farmers		2,000	2,000			8,000	18,000
Supplies [e]	U of MN	4,000	10,000	7,000	0	21,000	21,000
Sample Analysis [f]	U of MN	1,000	17,500	0	0	18,500	18,500
Total		42,000	177,000	65,000	116,000	400,000	400,000

a. U of MN (University of Minnesota)
   SFA (Sustainable Farming Association)
   LSP (Land Stewardship Project)
b. Personnel
   - Student internships for undergraduate student labor
   - Technicians and staff for conduct of research
   - Graduate Research Assistantship
c. Travel - travel to instate research sites
d. Contracts
   - Professional: Payment for services
   - Farmer: Payment for land use and labor
e. Supplies - Seed, fertilizer, plant materials, field plot supplies
f. Sample Analysis - Laboratory analysis of plant, soil and water samples

1. Legume Cover Crops in Northwest Minnesota.

Abstract:
The unique environment of Northwestern Minnesota, with a short growing season and limited rainfall has restricted the diversity of cash crops available to farmers in the region. Small grains and sugar beets are relied upon to generate much of the farm income in the region. Recurring outbreaks of small grain pathogens are one consequence of the lack of crop diversity, and pose a serious threat to the welfare of farmers in northwest Minnesota. Another factor that reduces farm income is the cost of external inputs of agrichemicals and fertilizers needed to produce crops conventionally. Environmental costs of current production methods are seen in loss of soil through erosion by wind and water, and in contamination of surface and ground water resources. We propose research on intercropping legume covers with small grains as a cultural intervention to prevent the incidence of fusarium head blight in small grains. Potential benefits of legume covers in addition to disease prevention are soil protection, improvement of soil organic matter content and nutrient status, and suppression of weeds.

Background:
The value of legumes in crop rotations has been recognized for centuries. The principal benefit attributed to legumes in crop rotations is their contribution of mineral nitrogen to the soil (Badaruddin et al, 1989; Baldock et al, 1981). In addition to fertility benefits, legume covers provide soil protection from rain impact, reducing runoff by improving water infiltration rates. Additional organic material provided by legume covers improves soil structure and increases its stability (Biederbeck, 1994).

A potential benefit of legume covers in small grains is a reduction in the severity of fusarium head blight (scab) (*Fusarium graminearum*). Ground cover provided by interseeded legumes may reduce dissemination of and infection by disease causing spores at the soil surface. In 1997, 2.5 million acres of spring wheat were planted in the Minnesota – most of it in the northwest. Over the past 5 years, scab has severely impacted spring wheat yields in the region. It is estimated that Minnesota wheat and barley producers suffered a $300 million loss in 1997 alone. It is also estimated that the scab epidemic has cost wheat and barley producers in North Dakota and Minnesota $4.2 billion dollars in the last 5 years (McMullen, 1994; Bai, 1994; Lyons, 1997; Brashier, 1996). Losses due to this disease are expected to mount unless disease resistant cultivars can be developed.

Until resistant cultivars can be developed, alternative crops or cropping systems will be the primary defense against the scab epidemic. Legumes covers seeded simultaneously with wheat will cover the soil before wheat reaches anthesis. This soil cover may provide a barrier to infection of developing wheat by scab inoculum from soil and plant residue. Before the advent of crop protection chemicals, crop rotation and diversification were standard interventions for reduce insects, diseases, and weeds. By adding new innovations to these historically proven methods, it may be possible to address crop pest problems that are currently impacting agriculture (Liebman, 1988).
Due to the availability of low cost nitrogen, the use of legumes in rotational systems for green manure purposes has greatly decreased (Badaruddin, 1990). Current farm economics discourage the use of a fallow year to produce a green manure crop. However, recent findings have shown

that it may be possible to grow a legume crop simultaneously with a cash crop (Kandel et al, 1997; Hesterman et al, 1992; Moynihan, 1996) thereby eliminating the need for a fallow year in the rotation. By interseeding legumes into existing crops, some of the benefits of having legumes in the rotation can be achieved without a lost production year. Some interseeded legume species receive enough light early in the season to successfully establish before the primary crop canopy intercepts all available sunlight. The legumes covers are then in place to make use of light available late in the season when the primary crop begins to senesce (Fukai, 1993).

Hard red spring wheat, sunflowers, and corn are widely grown crops in Northwest Minnesota. Understanding how to successfully interseed these crops with legumes could significantly improve these production systems. The integration of legumes will improve these cropping systems by providing biologically fixed nitrogen, extensive ground cover to reduce erosion, improved soil organic matter, tilth, and interuption of pest life cycles. Kandel et al. (1997) studied several legumes interseeded into sunflowers at various sunflower growth stages in North Dakota. They concluded that the best legume biomass production without decreasing sunflower yield was obtained with hairy vetch interseeded at the V4 sunflower growth stage. Brandt et al. (1989) in a study in Texas found that four subterranean clovers interseeded with wheat decreased wheat grain yields the first year, but increased grain yields the second year, apparently due to N symbiotically fixed by the clovers. Little is known about interseeding corn with legumes in Northwest Minnesota.

Fukai and Trenbath (1993) concluded that results from intercropping experiments often are site specific and that seasonal variation is high. Many cultural and environmental factors seem to influence the relative competitiveness of component crops. For this reason, our research will investigate varied cover species or ecotypes and cultural practices with the goal of identifying combinations that are best adapted to specific farming regions in Minnesota.

The objectives of this proposed research will be to identify legume covers that can be integrated into current production systems and replace chemical or mechanical solutions to production problems with biological solutions.

Methods:

***Objective 1*:** Determine the suitability of four hairy vetch ecotypes as covers for crop production in northwestern Minnesota. Compatibility of each vetch ecotype will be determined by: 1) Winter survival, and biomass production of the vetch; 2) Ability of vetch to provide utilizable resources to a succeeding corn crop; 3) Measurement of the amount of supplemental N provided by each vetch ecotype.

Experimental Design:

A two year study using randomized complete block plot design with four replications will be conducted at farm sites in Northwest Minnesota.

A split-plot restriction will be imposed on rotation with either wheat-corn or soybean-corn rotations being evaluated at each location.

Plot size will be 30 x 50 feet

Whole Plot Treatments:

- Soybean/Corn Rotation. Vetch surface seeded into standing soybeans in early August 1999. Cover incorporated into soil with disk or field cultivator around May 15, 2000. Corn planted around May 25, 2000.

- Wheat/Corn Rotation. Cover crops seeded into small grain stubble in early August 1999. Cover incorporated into soil with disk or field cultivator around May 15, 2000. Corn planted around May 25, 2000.

SubPlot Treatments:

- no cover /no fertilizer
- no cover /recommended N applied
- vetch ecotype #1
- vetch ecotype #2
- vetch ecotype #3
- vetch ecotype #4
-

Experiment Locations:

- On-farm sites in Northern Minnesota: 1 organic farm (Derosier farm)
- On-farm sites in Western Minnesota: 1 organic farm (Fernholz farm)

Data to be Collected and Analysis:

- Stand density and visual estimates of ground cover of vetch covers will be measured in fall and spring.
- Fall and spring vetch dry matter and N yield.
- Corn biomass at 4 weeks and 8 weeks after planting and at physiological maturity.
- Grain yield of corn.
- Corn nutrient (macro and micro minerals) status will be evaluated by leaf sampling at anthesis.
- Soil nitrogen status will be monitored by sampling in the late fall of 1999, at planting time in the spring of 2000, and at 30 day intervals thereafter until the corn or sunflower crops reach physiological maturity.
- Weed and disease development will be monitored in each system.

Objective 2: Evaluation of perennial legume cover systems for: 1) disease prevention, specifically fusarium head blight of small grain, 2) soil protection provided by legume covers in fall and spring, and 3)legume biomass and biological N produced by covers.

Experimental design:

A two year study will be initiated at two locations in the spring of 1999. Wheat or barley will be interseeded with three legume covers; in 2000 legumes will be sampled for biomass production and biological nitrogen availability to a second year crop will be estimated.

Experiments at each location will have a randomized complete block design with four replications. Plots will be 30' x 50' in size.

Treatments:

- Small grain interseeded with alfalfa.
- Small grain interseeded with red clover.
- Small grain interseeded with hairy vetch.
- Small grain without legume cover.

Locations: University Experiment Stations at Crookston, and Roseau, MN.

Data to be collected:

- Disease incidence, especially head scab and leaf diseases will be determined by observation of developing small grain and by analysis of harvested grain.
- Legume and spring wheat stand and height will be measured at 30 days after planting (DAP), 60 DAP, and just before harvest.
- Small grain yield, protein, and test weight will be measured.
- Legume N production will be determined by legume biomass production (1 m^2 sample per plot) and soil and plant analyses.
- Visual estimates of legume ground cover in the fall of 1999 and the spring of 2000.

Objective 3: Evaluation of the productivity of alternative rotations with forage seed species. Perennial forages that normally do not produce seed until the second year will be seeded simultaneously with wheat, soybean or flax in 1999. By using this interseeding technique, forages can be inserted into rotations without loss of production, as they functionally become single season crops. Forages will be harvested for seed in 2000. Effect of alternative rotations on crop yields, weed populations, fall and spring soil cover, and on soil moisture will be measured.

Experimental Design:

A two year study will be initiated at two experiment stations sites in the fall of 1999. Experiments will be planted in May, 1999.

Experiments will have a randomized complete block design with four replications. Plots will be 15 x 30 feet.

Treatments:

1999 Crop	2000 Crop
Birdsfoot trefoil seeded with spring wheat.	Birdsfoot trefoil seed.
Birdsfoot trefoil seeded with soybean.	Birdsfoot trefoil seed.
Birdsfoot trefoil seeded with flax.	Birdsfoot trefoil seed.
Red clover seeded with spring wheat.	Red clover seed.
Red clover seeded with soybean.	Red clover seed.
Red clover seeded with flax.	Red clover seed.
Perennial ryegrass seeded with spring wheat.	Perennial ryegrass seed.
Perennial ryegrass seeded with soybean.	Perennial ryegrass seed.
Perennial ryegrass seeded with flax.	Perennial ryegrass seed.
Spring wheat alone.	Spring wheat.
Soybean alone.	Spring wheat.
Flax alone.	Spring wheat.
Birdsfoot trefoil seeded alone.	Birdsfoot trefoil seed.
Red clover seeded alone.	Red clover seed.
Perennial ryegrass seeded alone.	Perennial ryegrass seed.

Locations: University Experiment Stations at Crookston and Morris, Minnesota.

Data Collected:

- Ground cover will be measured by visual estimate in the fall shortly before killing frost, and in the spring prior to cover suppression treatment.
- Cover biomass yield will be measured in fall and spring.
- Weed species identification and biomass at 1 and 3 months following soybean planting.
- Available soil water in each subplot will be measured to a 12 inch depth each week.
- Soybean growth and development will be measured on a weekly basis. Soybean seed yield will be measured after physiological maturity
-

Timetable for completing the proposed research.

Objective 1. Identify Hairy Vetch Ecotypes that Positively Influence Crop Productivity.

Summer-Fall 1999:	Site preparation, establishment of hairy vetch and rye covers.
Fall-Winter 1999:	Collect data on cover establishment.
Spring 2000:	Spring cover and biomass measurements. Application of N fertilizer to fertility standard plots. Cover suppression treatments. Corn planting.
Summer-Fall 2000:	Soil and plant sampling for nitrogen content. Corn yield measurement.
Winter 2001:	Analysis of data, preparation of reports.

Objective 2. Evaluation of Perennial Legume Cover System for Small Grain Production

Spring 1999:	Site preparation, establishment of small grain-legume interseeds.
Spring -Fall 1999:	Year 1 data collection for disease incidence, small grain yield, fall legume cover and biomass production.
Spring 2000:	Spring cover evaluations
Winter 2001:	Analysis of data, preparation of reports.

Objective 3. Evaluation of the Productivity of Alternative Rotations with Forage Seed Species.

May 1999:	Site preparation, seeding of crops.
Fall 1999:	Yield data for 1999 crop, fall ground cover, and forage species stand measurement.
Spring 2000:	Data collection for winter survival of forage seed crop. Wheat seeded for non-forage rotations.
Summer-Fall 2000:	Forage seed harvest and yield determination.
Winter 2001:	Analysis of data, determination of overall productivity of each rotation. Preparation of reports.

Description of the results and products produced from the proposed research.

Participating growers will obtain experience with interseeding of various legumes in most major crops grown in northwest Minnesota to protect soil, add biologically fixed nitrogen and organic matter to the soil. Various legumes will be evaluated to determine which are most appropriate for ease of establishment, ground cover, and biomass production when interseeded with spring wheat. Field days will be conducted at experiment locations to provide educational opportunities for growers and researchers. Results will be documented in publications that can be used as resources and training materials.

PROJECT EDUCATION PROGRAM:

We will conduct summer field days each year to describe the research and its impact. We will also present the results of the research at meetings throughout the year. We will develop popular and scientific publications that describe the research.

Project Budget:

Budget Item	**Organization**	**LCMR Cost**	**In-Kind**
Personnel:			
J. Wiersma	U of MN		$7,500
E. Oelke	U of MN		$7,500
Student Internships	U of MN	$27,000	
DeEtta Bilek	SFA	$ 4,000	
Other			
Travel	U of MN	$ 4,000	
Farmer stipend support		$ 2,000	
Analyses of samples	U of MN	$ 1,000	
Supplies	U of MN	$ 4,000	
Total:		$42,000	$15,000

Cooperators:

Scientists: Joachim Wiersma, Ervin Oelke Donald Wyse
Non-profits: DeEtta Bilek, Sustainable Farming Association.
Producers: Jaime Derosier, Farmer, R.R. 1 Box 310, Red Lake Falls, MN 56750.
Participants: Carmen Fernholz, Farmer, R.R. 2, Box 9A, Madison, MN 56256

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2. Cover Crops in Southern Minnesota

ABSTRACT

Lack of crop diversity across much of southern Minnesota has contributed to increased economic risk for producers, increased farm size, a declining rural population, a greater reliance on agrochemicals, a lack of infrastructure adequate to handle crops other than corn and soybeans, and impaired soil and water quality. Utilizing both on-farm and experiment station replicated research trials, this component of the LCMR proposal will investigate the impact of using cover crops and green manuring techniques in Minnesota to reduce nitrate losses through tile drainage and to diminish the abundance of weed, insect and disease pests associated with the simplified corn/soybean cropping system.

INTRODUCTION

The lack of crop diversity across much of southern Minnesota is very apparent. Heavy reliance on corn and soybean in the region may create severe production problems, similar to those experienced by small grain farmers in northwestern Minnesota during recent years. Regionally, crop and livestock diversity have steadily declined in recent decades, resulting in increased risk for producers from climatic factors, a shift in pest pressures requiring greater reliance on expensive and potentially harmful pesticides, lack of infrastructure for marketing crops other than corn or soybean, and low profit margins requiring increases in farm size to ensure profitability. Research has shown that the corn/soybean rotation is "leaky" for nitrates and other chemical inputs, which damages soil and water quality. Environmental quality is also lost by a reduction of esthetic appeal and wildlife diversity and abundance, reducing the recreational value of Minnesota landscapes. Finally, large-scale production of a narrow range of crops appears to be threatening the well-being of rural communities, due to losses of population, local enterprises, and vital social institutions such as schools.

It is known that diversified crop rotations can improve nutrient cycling, hydrological functioning, soil tilth, and regulation of pest populations, thus addressing many of the production and environmental consequences of current corn-soybean cropping (Bullock, 1992; Karlen et al., 1994; Brust and King, 1994; Jordan and Hutcheon, 1996). However, diversification of rotations by introducing new crops into existing rotations is a slow process requiring development of markets for these crops, infrastructure for handling, agronomic support and other elements. Clearly, introducing more plant diversity into currently-dominant corn-soybean and small grain cropping systems is a critical need. These systems are likely to remain dominant in the short- and medium-term, and therefore their agroecological functioning must be improved, and additional crops must be integrated when this is economically feasible.

Again, improvements are needed in nutrient cycling, hydrological functioning, soil tilth and regulation of pest populations. The integration of cover- and green-manure crops into existing short-rotation cropping systems is likely to improve these systems in these respects (Curran et al., 1994; Stute and Posner, 1995; Torbert et al.,1996). The goal is short rotations in which cover- and green manure crops provide plant diversity needed to produce ecological benefits typical of longer rotations. Cover crops have considerable potential to provide these ecological benefits (Lal et al., 1991), e.g., by retention of nutrients such as nitrogen (Shennan, 1992; Shipley et al., 1992), reduction of soil erosion and water runoff by physical protection of soil (Edwards et al., 1993) and improvements in soil tilth and quality, and suppression of insect, disease and weed pests by a wide variety of mechanisms (Bugg, 1992).

However, the challenge is to manage cover and green manure crops so that these provide ecological benefits without significantly hindering cash-grain production in existing corn-soybean and small-grain short rotations (Ranells, 1993). Specifically, cover crops are frequently difficult to establish, and often will suffer competitive suppression by cash-grain crops. When cover- and green-manure crops fail to establish or are competitively suppressed, their agroecological functioning is impaired or prevented. Conversely, these crops can successfully compete with cash crops for essential resources, causing economic losses (Power et al., 1991; Moomaw 1995; Keeling et al., 1996; Adbin, 1998), or cause other production problems (Buntin et al., 1994). Currently, most farmers regard use of cover- and green-manure crops as complicated, unreliable and risk prone. Effective management approaches that permit cover- and green-manure crops to work well must be devised on a region-, and in some cases, site-specific basis.

The proposed work will study use of cover- or green-manure crops at a variety of points in the corn-soybean rotation (Stute and Posner, 1993), and assess their agroecological functioning (Power, 1991) and compatibility with cash-grain production. By addressing these two critical dimensions of cover- and green-manure crops, we hope to improve understanding of how these crops can be used to effectively diversify the corn-soybean cropping system of southern Minnesota. Specifically, we will document how integration of these crops into the corn-soybean rotation affects nitrogen losses to surrounding ecosystems, soil-borne pests of soybean, and yield of subsequent crops. We believe that this work will significantly reduce current barriers to use of cover- and green-manure crops in the corn-soybean cropping system. We will also investigate the integration of undersown legumes into small grains grown before corn, to help develop this promising cropping system for southern Minnesota. Following is a description of a program of five experiments addressing these issues.

I. REDUCING NITRATE LOSSES WITH A SCAVENGER CROP

1. Background:

The climate and soil of southwest Minnesota, coupled with skilled management by producers, has routinely resulted in high corn and soybean yields. However, the rotation itself and certain associated management practices (e.g., tile drainage, intensive tillage) have shown evidence of negative environmental impacts, particularly on water quality. In a study conducted at the Southwest Experiment Station at Lamberton, for example, nitrate-N concentrations in tile drainage effluent from both corn and soybean plots consistently exceeded the maximum allowable level of 10 mg NO_3-N/L, sometimes by as much as 200-400% (Randall et al., 1997), despite use of best management practices for N application (Rehm et al., 1996). Studies of NO_3-N leaching loss comparing corn and soybeans with small grains or forages suggest that the "leakiness" of corn and soybean is due in part to their shallow, relatively coarse root systems and to the fact that they are either no longer present or not actively growing during periods of likely tile drainage flow (Eltun, 1995; Randall et al., 1997).

Certain grasses (e.g., small grains) which have extensive fibrous rooting systems and deep-rooted perennial legumes (e.g., alfalfa) are known to be excellent scavengers for soil N (Brinsfield and Staver, 1990; Eltun, 1995; Brandi-Dohrn et al., 1997). A promising method of reducing nitrate leaching is to introduce winter cover crops into the existing two-year corn/soybean rotation to effectively scavenge for nitrate N. An example of this would be to plant a cover crop into corn, after corn planting but prior to corn canopy closure. The cover crop would survive under the corn canopy and then thrive in the fall after corn harvest and in the spring prior to soybean planting. This strategy might be more palatable to growers concerned about planting relatively low-value commodities. Studies in New York (Scott et al., 1987), Iowa (Exner and Cruse, 1993), and Quebec (Abdin et al., 1998) have documented that cover crops with scavenger potential can be established in standing corn without reducing corn yield. These same studies suggest, however, that cover crop species selection and date and methods of interseeding are highly dependent on climatic and edaphic factors, and therefore must be developed on a regional basis. Documented work on cover crop interseeds for use in Minnesota has so far been restricted to only two species, yellow mustard (*Brassica hirta* Moench 'Kirby' (De Haan et al., 1994) and winter rye (*Secale cereale* L.) (Reicosky and Warnes, 1991). Although promising, these studies suggest that further work is needed on species identification and management practices for successful use as scavenger species.

Objectives: 1) Reduce the loss of nitrate-N from subsurface tile drainage under the corn/soybean crop sequence with scavenger crops, and 2) screen potential nitrate-N scavenger crops for corn/soybean systems.

2. Methods:

Objective 1: Reducing the loss of nitrate-N from subsurface tile drainage under the corn/soybean crop sequence with scavenger crops.

Experimental design: A trial in which a scavenger crop is introduced into a corn-soybean rotation was initiated in 1998. The design is a randomized complete block design with four replications. The research utilizes 16 subsurface tile drainage plots. Annual ryegrass is used as the scavenger crop, and it is broadcast seeded into standing corn at the eighth leaf stage. The treatments include:

Corn - soybean - corn - soybean.
Soybean - corn - soybean - corn.
Corn plus scavenger crop - soybean - corn plus scavenger crop - soybean.
Soybean - corn plus scavenger crop - soybean - corn plus scavenger crop.

Data to be collected:
- Tile-line effluent and the soil will be analyzed for nitrate-N in each year of the rotation. The tile-line effluent is sampled every-other-day throughout the year when the tiles flow, and flow rate and nitrate-N concentrations are obtained. Soil samples for nitrate-N are taken to a depth of five feet after harvest.
- Corn, soybean, and annual ryegrass dry matter and nitrogen yield in the fall when corn and soybeans reach physiological maturity.

Biological data will be analyzed using standard analysis of variance procedures.

Location: Southwest Experiment Station, Lamberton, MN

Objective 2: To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment I. Alternative crops seeded into corn

Cover crop and planting date combinations:

a) Annual ryegrass after last cultivation
b) Annual ryegrass after tasseling
c) Red clover after tasseling
d) Oat after tasseling
e) Winter rye after tasseling
f) Control: no cover crop planted

Data to be collected:

1) Standard soil tests for P, K, org. matter and pH at each site
2) Cover crop stand counts at 4 weeks after planting date
3) Crop yield
4) Cover crop aboveground biomass accumulation and N and P tissue content before first frost or killing frost
5) Cover crop spring biomass and N and P tissue content before incorporation or kill
6) Early spring soil nitrate-N content at 0-2 and 2-4 foot depths

Locations:

1) Southwest Research and Outreach Center, Lamberton, Redwood County
2) Doug Moody Farm, Cottonwood County
3) Chad and Mark Coulter Farm, Cottonwood County
4) Phil Batalden Farm, Cottonwood County
5) Steve Halter Farm, Cottonwood County

Experiment II. Cereal rye cover variety crop evaluation

Based on the success of rye as a scavenger, a screening of cultivars will occur. This research, to be initiated in the fall of 2000, will evaluate 4 cereal rye cultivars at Experiment Stations at Lamberton, Waseca, and Morris in replicated trials.

Data to be collected:

1) Fall and early spring biomass and N yield

3. Timetable:

Spring 1999:	Initiate 2nd year of scavenger trial, and corn and soybean underseed satellite trials.
Summer-Winter 1999:	Collect tile-line effluent samples in scavenger trial. Analyze 1999 water and soil samples for nitrate-N.
Spring 2000:	Initiate 3rd year of scavenger trial, and corn and soybean underseed satellite trails.
Summer-Winter 2000:	Collect tile-line effluent samples in scavenger trial. Analyze 2000 water and soil samples for nitrate-N.
Spring 2001:	Results from the season compiled and summarized for delivery at Winter Crops Days and other outreach activities.

4. Results and Products:

≃ Information on the efficiency of an annual ryegrass scavenger crop on nitrogen loss from the system.
≃ Recommendations on the most effective scavenger crops in corn and soybean systems.

II. EVALUATING LEGUMES INTERCROPPED IN SMALL GRAINS

1. Background:

Production practices of corn and soybean in southern Minnesota has evolved over time to take advantage of the relatively limited growing season this region provides. Both crops now push the limit of the growing season, offering little obvious opportunity for integrating short-duration, environmentally friendly covers into this system. For example, fall-seeded cover crops, planted after corn or soybean harvest, are unreliable in this region because of variable moisture availability and stand loss due to cold temperatures (Warnes et al., 1989). A logical means of introducing certain cover crop species is underseeding into small grains or interseeding into corn or soybean.

A number of agronomic issues arise when introducing cover crops in this fashion. First, optimal establishment will require an appropriate relationship with cash crops, without excessive suppression of either cover or cash crop (Power et al., 1991; Moomaw, 1995; Keeling et al., 1996). Cover establishment times are likely to affect this relationship, and optimal times are likely to vary among cover-crop species, sites and years. Secondly, the cover crop should have desirable effects on pest infestations (Buntin et al., 1994; Curran et al., 1994). Finally, certain management factors may be important in successful establishment and functioning of covers. For example, crop variety selection may affect cover crop growth after crop maturity, and earlier varieties may boost cover crop performance at a moderate yield cost, providing a net benefit. Also, soil management (e.g., organic matter inputs) appears to affect establishment of undersown covers (D. Buhler, unpublished data).
Objective: To determine the effect of intercropped forage legumes on small grain yield, legume N production, and yield of a subsequent corn crop.

2. Methods:

A. Experiment station trial:

Experimental design: A 2-year experiment will be conducted in which legumes will be intercropped with wheat in year 1 and corn grown after legume after legume plow-down in year 2.

Treatments include:

- Tillage: two small grain tillage/establishment approaches (no-till planting of the small grains vs. planting following disking) instead of the original 1 (disking)
- Small grain species: two small grains (wheat and oats) instead of the original 1 (wheat)
- Forage legume species: 'Nitro +' alfalfa, Mammoth red clover, 'Bigbee' berseem clover, yellow sweetclover, and Santiago bur medic

Data to be collected:

≈ Legume and small grain populations at 4 weeks following seeding.
≈ Biomass, and N accumulation of the forage legume and weed species at small grain harvest.
≈ Small grain yield at harvest.
≈ Grain and stover dry matter and N yield of a subsequent corn crop.
≈ Biological data will be analyzed using standard analysis of variance (ANOVA). Economic net return from each treatment will be determined by considering fixed and variable inputs and gross returns.

Location: Southwest Experiment Station, Lamberton, MN

B. On-farm trials:

Experimental design: In experiments similar to those described above, annual medic, alfalfa, and berseem clover will be established with and without wheat in year 1. A corn crop will be grown in year 2. The experimental design will be a randomized complete block with two replicates at each location. Field scale plots of one or more acres, a standard producer production practice will be used.

Data to be collected:

≈ Legume and small grain populations at 4 weeks following seeding.
≈ Biomass, and N accumulation of the forage legume species at small grain harvest.
≈ Small grain yield at harvest.
≈ Grain and stover dry matter and N yield of a subsequent corn crop.
≈ Biological data will be analyzed using standard analysis of variance (ANOVA). Economic net return from each treatment will be determined by considering fixed and variable inputs and gross returns. Economic comparisons of the treatments will also be conducted.

Locations:
Carmen Fernholz, Madison in Lac Qui Parle County; Larry Olsen, Montevideo in Chippewa County; Eldon Mitzner, Tracy in Lyon County; Don DeWeerd, Pipestone in Pipestone County. Plainview in Wabasha County. An-farm experiment will compare legume covers seeded after removal of field peas in mid-July. We will measure fall nitrogen and dry matter production of the legumes.

3. Timetable:

Spring 1999:	Establish on-station trial with wheat and legume underseeds. Establish on-farm field scale wheat and legume underseed studies.
Summer-Fall 1999:	Harvest wheat and monitor legume underseeds.
Winter 1999:	Summarize 1999 growing season results. Issue preliminary report.
Spring 2000:	Plant corn in wheat/legume underseeds trials initiated in 1999. Establish on-station trial with wheat and legume underseeds. Establish on-farm field scale wheat and legume underseed studies.
Summer-Fall 2000:	Harvest wheat and monitor legume underseeds.
Spring 2001:	Final report.

4. Results and products:

≃ Information on the impact of intercropped legumes on yield of small grains and subsequent crops in diverse environments.
≃ Extension and popular publications on use of legume intercrops.

III. KURA CLOVER AS A PERENNIAL LIVING MULCH

1. Background:

The use of perennial "living mulches" for intercropping in reduced or no-tillage systems provides the opportunity for year-round soil cover and alleviates concerns about poor establishment and costs due to annual seeding of crops. An effective system for grain production should provide suppression of the legume during grain crop germination and early-season growth but allow for sufficient legume recover for soil cover during fall and winter (Hall et al., 1984). Although living mulches can suppress weed invasion and growth by competing for light, water, and nutrients (Mayer and Hartwig, 1986), they can also provide competition for the primary crop. For example, Schultz et al. (1987) seeded corn into stands of several legumes and reported that with about 50% of legume cover retained, maximum corn silage yield was 74% of that in chemically killed sod. In the eastern USA, where rainfall usually exceeds levels in Minnesota, yields have sometimes been increased or were similar to those for conventionally grown corn (Mayer and Hartwig, 1986).

Perennial legumes typically used in the Midwest for forage and soil conservation are crown formers, such as alfalfa, or clone formers that can asexually regenerate, such as white clover or Kura clover (Beuselinck et al., 1994). Crown formers are less adapted to a long-term living mulch system because they cannot regenerate if parent plants are injured by suppression, and because an upright growth habit can be more competitive for light and water than more prostrate clonal species (Eberlein et al., 1992). Among the perennial, clone forming species that spread by stolons such as white clover (Vrabel et al.,1980) and rhizomes such as crown vetch (Mayer and Hartwig, 1986) have been used effectively as perennial living mulches. However, these legumes lack winterhardiness to reliably persist in Minnesota. More recently, Kura clover, a perennial legume with an extensive below ground root-rhizome system, has been evaluated as a living mulch in Wisconsin. Zemenchik et al. (1998) reported that with adequate suppression, a Kura clover living mulch suppressed weeds, did not reduce corn yields, and recovered to full production within 12 months. In Minnesota, stands of Kura clover have persisted for over 15 years under frequent grazing, but Kura clover has not been evaluated as a living mulch for corn or other crops under Minnesota conditions. In addition, the competition for resources in the Kura clover living mulch system has not been studied.

2. Methods:

Objectives: For a system where corn will be seeded into established stands of Kura clover we will determine: 1) corn and soybean grain yields; 2) Kura clover seed and forage production in the year following intercropping; 3) weed inhibition in corn, when intercropped with Kura clover; 4) soil moisture, soil nitrogen, and plant nutrient status.

<u>Experimental design</u>**:** Randomized complete block design with treatments in split-plot arrangement. Whole plots will be tillage treatments and sub-plots will be Kura clover suppression and N fertilizer treatments. Each experiment will be 2 years in duration. In year 1, we will establish grain crops into established stands of 3-year-old Kura clover. In year 2, we will evaluate the impact of the first year of grain crops on forage and seed years of Kura clover.

Whole Plot treatments:

Fall tillage with chisel plow with kura clover suppressed with Rouind-up herbicide
Spring tillage with chisel plow with kura clover suppressed with Round-Up herbicide

Split-plot treatments:

- Nitrogen (100 lb/acre)
- 0 Nitrogen

Locations: Rosemount and Becker, MN.

<u>Data to be collected:</u>
- Yield of corn after physiological maturity.
- Yield of Kura clover at 1 and 3 months following spring planting of crops and in the fall of the seeding year.
- Yield of Kura clover forage in the year following seeding.
- Weed species yield and identification 1 and 3 months following crop planting.

- Soil N status
- Biological data will be analyzed using standard analysis of variance (ANOVA). Economic net return from each treatment will be determined by considering fixed and variable inputs and gross returns.

3. Results and products:

- Information on use of the Kura clover living mulch system.
- Extension publications on use of the Kura clover living mulch system.

4. Timetable:

Fall 1999:	Application of fall tillage treatments.
Spring 2000:	Application of tillage, suppression, and N treatments. of corn, soybean.
Spring-Fall 2000:	Collection of weed, Kura clover, corn yield data.
Winter 2001:	Data summary and analysis.
Spring 2001:	Reestablish trial; Develop report

Project Education Program:

We will conduct summer field days each year at Experiment Stations and on-farm sites to describe the research and its impact. We will also present the results of the research at winter meetings. We will develop popular and scientific publications that describe the research.

Project Budge	Requested	In-Kind
Personnel:		
Student internships	$14,000	
Technician	$60,000	
DeEtta Bilek	$10,000	
Richard Ness	$17,000	
Deborah Allan		$ 5,000
Kevin Betts		$ 5,000
Elizabeth Dyck		$ 5,000
Nicholas Jordan		$ 5,000
Paul Porter		$15,000
Steve Quiring		$ 5,000
Craig Sheaffer		$10,000
Don Wyse		$15,000
Research Assistantship (1)	$40,000	
Travel	$ 2,000	
Supplies		
U of MN	$12,000	
Farmer stipend support	$ 2,000	
Analyses	$20,000	
Total	$177,000	$65,000

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COOPERATORS

Scientists:

Dr. Deborah L. Allan, Professor, U of MN, Dept of Soil, Water, and Climate
Dr. Elizabeth Dyck, Asst. Prof., U. of MN, Lamberton, and Southwest State Univ., Marshall, MN.
Dr. Nicholas Jordan, Assoc. Prof, U of MN, Department of Agronomy and Plant Genetics
Dr. Paul Porter, Assoc. Prof., U of MN, Department of Agronomy and Plant Genetics
Dr. Michael Russelle, Prof and Soil Scientist, USDAA-ARS, St. Paul, MN
Dr. Craig Sheaffer, Professor, U of MN, Dept of Agronomy and Plant Genetics
Dr. Donald Wyse, Professor, U of MN, Dept of Agronomy and Plant Genetics.

Non-profits:

Mr. Richard Ness, Coordinator of the Farm Beginnings Program and Monitoring Program, Land Stewardship Project. They have been involved in project planning and will work with farmer cooperators to facilitate on-farm research.
Ms. Dietta Bilek, Program Coordinator, SFA.

Producers:

The following producers will participate in on-farm research. They have been involved in planning as related to their farms.
Phil Batalden, Lamberton, Cottonwood County
Steve Halter, Lamberton, Cottonwood County
Carmen Fernholtz, Madison, in Lac Qui Parle County
Jim Remele, Echo, Redwood County.
Jim Rogotzke, Sanborn, Redwood County.

3. Agroforestry Crops and Systems

1. Abstract: The goal of this project is to further develop hazelnuts that provide environmental and economic benefits and that can be widely incorporated into agricultural landscapes. This concept of incorporating woody plants into agricultural systems is known as agroforestry. Agroforestry is an intensive land management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or animals (Garrett et al., 1996).

Hazelnuts have been chosen for this study because of the market potential of their products and because considerable research has already been completed on these species. However, varieties of these species have not been tested on a widespread basis in Minnesota—a crucial step needed to realize the potential of these species in agricultural landscapes. This project will test varieties of hazels to identify superior varieties for specific conditions. It will also test a variety of establishment practices to discover what practices work best.

2. Background: Agriculture's impact on natural resources has received a great deal of attention in recent years, particularly in terms of its effects on the nation's streams, rivers, lakes, and groundwater. In the Upper Midwest there is a growing interest in utilizing woody plants as a means to ameliorate some of agriculture's negative effects on the environment. At the same time, producers are actively searching for profitable crops and production systems to diversify their farming operations and thus reduce their risk (Joannides, 1997). Under-utilized and potentially profitable supplements to traditional crops and cropping systems are woody plants that can produce food, fiber, and biomass. The woody plants can be incorporated into agricultural systems as agroforestry plantings such as field windbreaks, living snowfences, or riparian buffers.

The concept of incorporating woody plants into agricultural systems is known as agroforestry. Agroforestry is an intensive land management system that strives to optimize the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or animals (Garrett et al., 1996). While agroforestry practices have been adopted to some degree for conservation reasons, there is a general consensus that these practices will not find widespread adoption until their profitability is obvious.

Hazelnuts have been chosen because considerable research has already been completed on them and because of the market potential of their products. Hybrid hazelnut varieties have been under development at Badgersett Research Farm in SE Minnesota for the past twenty years. Now that high-performance genetic material has been developed, these hazels are attracting great interest from landowners. The hazelnuts developed at Badgersett have been bred to be hardy to Minnesota's climate, resistant to Eastern Filbert Blight, and able to produce nuts on a commercial scale (Rutter, 1988). The hazelnut industry is well-established in other parts of the world. Hazelnuts are marketed in unshelled and shelled forms, roasted or salted, and are currently used primarily in the confectionery industries, and for the preparation of several food products. Presently the principal hazelnut-producing countries are Turkey, Italy, Spain, France, and the United States. Approximately 60% of the world's hazels are produced by Turkey

(Azarenko, 1994). In the United States, 99% of hazels are grown in the Pacific Northwest; yet this area meets only 10% of the domestic hazelnut market demand. Currently there has been no commercial production in the Midwest because until recently the only hazels well-adapted to this area were wild types which produce only small, inconsistent crops.

Hazelnuts have potential for incorporation into agricultural systems in Minnesota to provide environmental and economic benefits. However, cultivars have not been tested on a widespread basis in Minnesota. To realize the potential of these species in diversifying agricultural systems, a comprehensive program must be put into place to test varieties across a range of environments in Minnesota. The test plantings will serve as a source for plant material for future production.

The objectives of this research are:
1. Evaluate hybrid hazelnuts adapted for different areas and conditions.
2. Evaluate the effects of management practices in the establishment of hazelnuts.

3. Methods:

Objective 1: Evaluate superior varieties of hybrid hazelnuts to determine those best adapted for different areas and conditions.

Objective 2: Evaluate the effects of management practices in the establishment of hazelnuts.

Experimental design: Hazelnuts will be evaluated in diverse areas of Minnesota. Weed control alternatives (cultivation and organic mulch) will be applied at three locations. At two locations, improved populations will be evaluated.

Plant selection and planting:

- Hazelnuts from Badgersett Research Farm will be tested. Standard practices will be used for site preparation.
- Plantings will occur from May through June of 2000. All plantings will be monitored to ensure sufficient water supply during the establishment year. Needed water will be supplied via irrigation or water wagon.
- All plants will be fertilized according to nursery industry standards based on current soil fertility.
- Planting will be monitored for predation by rodents and other herbivores. Preventive measures will be applied.
-

Data to be collected:

Soil physical and chemical characteristics will be recorded prior to planting.
Climatic information will be collected from the closest meteorological station to each site

- Survival, average plant height and vigor, insect and disease occurrence, and damage from wildlife and herbicides will be monitored. Sites will be monitored at least once a month during the growing season over the first two years and more frequently during establishment in the first year of growth. The current grant request will cover the greatest expense in this research—the establishment costs of the test plots. However, after these funds expire we anticipate being able to secure additional funds in order to follow these plants to bearing maturity, when we will collect information on harvest yields and quality of the nuts and berries.

Locations:

West Central Experiment Station-Morris, Stevens County
Dennis Gibson Farm, Chippewa County
Southwest Experiment Station-Lamberton, Redwood County
Staples Irrigation Center, Staples, Todd County
Rosemount Experiment Station, Rosemount, Dakota County

4. Results and Products:

- Recommendations on varieties of hazelnuts for different soil and climatic conditions in Minnesota.
- Sites to serve as demonstrations and sources of seed and germplasm of the species tested.
- Information for those interested in growing and marketing hazels. A fact sheet on the use of hazels in Minnesota's agricultural systems will be developed to assist in disseminating the information gained from the study.

5. Timetable: Below is a tentative schedule to implement the major aspects of this project.

July 1999	• Take soil samples of sites
August 1999	• Prepares sites
Spring 2000	• Plant seedlings • Take soil samples of sites
June 2000	• Prepare sites
Remainder of growing season	• Follow-up aftercare and maintenance of sites • Sites will be monitored and data collected during the first six weeks of establishment
Spring 2001	• Check for survival and conduct maintenance as necessary • Follow-up aftercare and maintenance
Spring 2001	• Prepare project report

6. Budget

Category	Organization	Requested	In-kind Support
Personnel:			
Student internship(s)	U of MN	$7,000	
Technician (0.75)	U of MN	$45,000	
Faculty - Craig Sheaffer	U of MN		$5,000
Other:			
Prof/Tech Contracts	Private	$5,000	
MN Travel	U of MN	$1,000	
Plant Materials/Supplies	U of MN	$7,000	
Total:		$65,000	$5,000

7. Cooperators:

Producers: Philip Rutter, Proprietor, Badgersett Research Farm. Mr. Rutter owns and operates Badgersett Research Farm, a twenty year old private research facility dedicated to developing commercial-quality hybrid chestnuts and hazelnuts. This 40-acre research facility and full greenhouse is dedicated to testing, propagating and growing hazels. Mr. Rutter is a national authority on hazelnut production in the Midwestern. Mr. Rutter has partnerships with a number of research and education institutions in the U.S. and China. Mr. Rutter is a member of the Minnesota Agroforestry Coalition.

Dennis Gibson, Farmer. Mr. Gibson is a corn and sugar beet producer in Chippewa County. For the past ten years he has been incorporating trees into his farm. He planted 50 acres of hybrid poplar timberbelts in 1998. He is one of the first landowners in the country to establish a hybrid poplar timberbelt for the purpose of increasing yields on adjacent crops while producing marketable pulpwood. Mr. Gibson is actively involved in his community with issues related to water resources. He is a member of the Minnesota Agroforestry Coalition and the Hybrid Poplar Agroforestry Co-op.

8. References:

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4. Indigenous Legumes:

1. Abstract: Agriculture in the United States lacks diversity with approximately 80 percent of all row crop acres planted to wheat, corn and soybean. Indigenous legumes were important components of the diverse Minnesota grassland and prairie ecosystems. They present a unique opportunity to increase the diversity and profitability of modern agricultural systems by incorporating these native species into grazing systems. Native legumes are well-suited for grazing systems in the Midwest because they will even out the production of forage biomass across the growing season; increase the forage quality and yield of pastures; are adapted to floodplain environments; and have growth habits that compliment warm-season grasses. The objectives of this research are to evaluate establishment and persistence of two native perennial legumes (Illinois bundleflower and false indigo) in grazing systems and to initiate plant breeding programs for important agronomic traits in both species. Research will be conducted on-farm and at the University of Minnesota to evaluate establishment techniques and grazing management strategies. Plant breeding programs for false indigo and Illinois bundleflower will emphasize improving these species by selecting for forage yield, forage quality, seed yield, disease and insect resistance, persistence, and grazing tolerance.

2. Background: Indigenous legumes were important components of the diverse Minnesota grassland and prairie ecosystems and present a unique opportunity to increase the diversity and profitability of modern agricultural systems. Although a number of the perennial indigenous legumes have potential as alternative grain and biomass fuel crops, the most expedient use of indigenous legumes will be as new forage species utilized in grazing systems.

Illinois bundleflower (*Desmanthus illinoensis*) is a prairie legume with a native range extending north to Minnesota and North Dakota, southwest to New Mexico, and southeast to Florida. The Land Institute of Salina, Kansas has conducted research with this plant and considers it to have great potential as a perennial grain crop for human consumption. Several studies have also been conducted to evaluate its utility as a pasture or range plant. Illinois bundleflower does not begin to grow until early June, and is most productive during the month of July. The species has modest seedling vigor, but will produce a deep taproot, flower, and set seed in the first year (Hellwinckel 1992). The plant is often most productive in lowland sites with moist soils, but does also occur on dry upland locations (Towne and Knapp 1996). It has been tested by the USDA, and no toxic levels of oxalates, cyanides, nitrates, or alkaloids have been found in the seed or foliage (Kulakow et al. 1990). It has the ability to fix atmospheric nitrogen at rates similar to alfalfa or soybean (Kulakow et al. 1990). Seed yields in the central United States have been as high as 1513 lb/acre, with average yields of 1068 lb/acre; shattering is common, but plants with resistance to shattering have been discovered (Kulakow et al. 1990). Due to this heavy seed production, Illinois bundleflower will naturally reseed in a pasture (Dovel et al. 1990).

Illinois bundleflower establishment has been investigated. The first important step for successful establishment is seed scarification which increased germination from near zero to ninety percent (Carre and Cavigelli 1985). Dovel et al. (1990) studied the establishment of Illinois bundleflower in a Texas warm-season grass pasture, and its impact on rangeland production and quality. They found disking followed by broadcast seeding at 6 lb/acre to be an effective establishment method. Interseeding with Illinois bundleflower increased forage yield by 45 percent over unimproved pasture, and after four years the stand was still persistent, with Illinois bundleflower yielding over 2500 lbs/acre dry matter. Posler et al. (1993) also studied the potential for Illinois bundleflower as a forage species for mixture with warm season grasses in Kansas. They found that the plant drastically increased total forage yield, but slightly reduced in vitro dry matter digestibility as compared to grass alone. Most importantly, Illinois bundleflower in mixture with grass more than doubled the crude protein concentration in the mixture versus grass monoculture.

False indigo (*Amorpha fruticosa*) has been the investigated for its potential as a forage (Papachristou and Papanastasis 1994), and biomass energy crop (Roth, et al. 1984). This plant is a true shrub, producing woody stems that do not die back in winter. It is native to most of the continental United States, commonly occurring along rivers, streams, and lakes, but also in desert areas and on dry rocky outcroppings. We have observed it thriving in standing water and on extremely rocky prairie preserves in southwest Minnesota. False indigo is a warm-season legume. Its buds do not break dormancy in Minnesota until mid-May, but it grows rapidly during July and August (Lueschen 1997). It can grow about 1 meter in height per season, and at maturity has a square appearance with height and width of about 3 meters. It forms a deep tap root system that is heavily nodulated by nitrogen-fixing bacteria (Allen and Allen 1981). False indigo has yet to be utilized in North America as a forage, but it has been used in Mediterranean countries. One researcher from Pakistan states that it "is a nutritious fodder," (Sheikh 1979), while another asserts that "since no toxic component exists, these forages . . . are capable of supporting and growing calves and cows in milk" (Khan 1975).

Studies at the St. Paul research station have demonstrated the potential for rapid establishment of false indigo, with monocultured yields exceeding 3 tons of dry matter per acre in the second season (Lueschen 1996). Third year yield from plants that were harvested the preceding fall have exceeded seven tons of dry matter per acre, and contained 13.3 percent crude protein (Lueschen 1997). Plants harvested in the spring of the third year had crude protein concentrations over 20 percent (Lueschen 1997).

Alfalfa is going to be used in Minnesota as a renewable energy and protein source The leaf portion will be sold as a pelletized animal feed, and the stem portion will be burned to generate electricity. This biomass energy and protein system is scheduled to be operating in Granite Falls, Minnesota, by 2001 (MnVAP 1996). False indigo has potential to be more efficient and cost effective than alfalfa in this system. False indigo has yielded 1.8 tons of leaf material per acre, which is similar to alfalfa leaf yield, and leaf protein content was only slightly lower than alfalfa (Lueschen 1997). Additionally, false indigo has produced 5.5 tons of stem material during the third growing season (Lueschen 1997), which is about double alfalfa stem production. A system using false indigo instead of alfalfa would also be more efficient because stems would only have to be harvested once yearly, or perhaps even once every several years; furthermore, the separation and pelletizing steps could be eliminated because the animals could browse the leaf material directly from the plants, performing the separation in the field.

Grazing systems: The profitability and expansion of grazing systems is currently limited by several factors that may be overcome with the reintroduction of indigenous legumes. First, the productivity of our predominate, cool-season grass pastures in Minnesota is uneven with about two-thirds of the forage biomass being produced in the first one-third of the growing season. Several of the indigenous legumes including Illinois bundleflower (*Desmanthis illlinoensis*) and false indigo (*Amorpha fruticosa*) grow rapidly during the summer months and maintain high forage quality during the growing season when it is most needed by producers. Second, legumes have the ability to fix nitrogen which increases forage yield and quality of the pasture. The most commonly utilized legumes are often slow to establish and lack persistence. Illinois bundle flower and false indigo can establish rapidly, are productive in the seedling year, and are persistent. Third, farmers with low-lying or floodplain pastures cannot use current forage legumes because of high soil moisture and shade from vegetation. The legumes we are studying are found naturally in these types of environments and should be highly productive. The introduction of native legumes into these pastures should improve the profitability of the pastures and expand the use of controlled grazing along rivers resulting on a reduction in nonpoint source surface water contamination. Fourth, non-native legumes are incompatible with native warm-season grasses. Native legumes should be able to coexist and enhance warm-season grass pastures since they occur naturally in prairie ecosystems where warm-season grasses predominate. With 8 million acres of warm-season grasses previously established through the Conservation Reserve program, the addition of native legumes into these grasslands will enhance the yield, quality and profitability of grazing and thus reduce the conversion back to cropland.

The objectives of this research are:

1. To evaluate establishment and persistence of two native perennial legumes in grazing systems using a research and education network.
2. To initiate two native legume plant breeding programs.

3. Methods:

Objective 1: To evaluate establishment and persistence of two native perennial legumes in cool season grass pasture grazing systems.

<u>Experimental design:</u> randomized complete block design with two to six replications per location. Treatments include: Species: false indigo, Illinois bundleflower, alfalfa (control) and unamended pasture. Establishment methods: frost seeding and seeding with no-till drill. Grazing management strategies: will be determined cooperatively by the producers and the scientists to meet the needs of the livestock enterprise and the goals of the research project.

<u>Locations:</u> Research will be conducted on farms in Minnesota located in Lake City, Montevideo, Milan, and Rushford (Wilson) and the Sand Plain Research Center at Becker and the St. Paul Campus.

Data to be collected:

- Stand density of the legumes in the establishment year.
- Stand density of the legumes after two years of grazing.
- Dry matter yield of grasses, legumes, and invading weedy species in the pasture.
- Forage quality (fiber and energy content) of the biomass if present.

Objective 2: To initiate native legume plant breeding programs for Illinois bundleflower and false indigo.

Experimental design: randomized complete block design with four replicates per location. Separate experiments will be conducted for false indigo and Illinois bundle flower. Treatments will consist of 20 populations of each species collected from the upper Midwest. Each plot consists of 6 space-planted individuals; approximately 120 individuals measured per collection for a total of 5000 plants across locations for each species. Seedings will be monitored for predation by rodents and other herbivores. Preventive measures will be undertaken when necessary.

Locations: Plant nurseries will be established at the University of Minnesota Experiment Stations at St. Paul and Becker, MN.

Data to be collected:

- Individual plant measurements of growth habit, seed production, forage production, vigor, persistence, pest resistance and other agronomic traits.
- Determine the amount of genetic variability in the native legume populations for the important agronomic traits and estimate heritabilities of these traits to assist in the development of appropriate breeding strategies for Illinois bundleflower and false indigo.
- Begin initial selections among the native plant populations for the development of breeding populations for future variety development activities.

4. Results and Products:

Objective 1. To evaluate establishment and persistence of native perennial legumes in cool season grass pastures.

- Information on establishment and grazing management methods will be published and distributed.
- A native perennial legume web site will be constructed and maintained with the latest available information.
- Teams of researchers, nonprofit organizations, and farmers will meet annually to evaluate the species and research project on the basis of ability to establish, persistence under grazing, and productivity.

Objective 2: To initiate native legume plant breeding programs for Illinois bundleflower and false indigo.

- Plant breeding populations of false indigo and Illinois bundleflower will be developed with the potential for variety release of these native legumes for grazing.
- Basic genetic and agronomic information about false indigo and Illinois bundleflower for use in developing successful plant breeding strategies and agronomic research priorities.

Educational programs: Teams of researchers, nonprofit organizations, and farmers will host and participate in a minimum of three annual summer field days to demonstrate establishment and grazing management strategies for false indigo and Illinois bundleflower.

5. Timetable

***Objective 1*: To evaluate establishment and persistence of two native perennial legumes in grazing systems.**

Fall-Winter 1999:	Final site preparation and initiation of frost seeding treatments.
Spring 2000:	Planting and stand density evaluations
Summer-Fall, 2000:	Data collection, grazing, summer field days
Winter 2001:	Data summary and analysis
Spring-Fall, 2001:	Grazing, data collection, field days, data analysis

***Objective 2*: To initiate native legume plant breeding programs for Illinois bundleflower and false indigo.**

Summer 1999	Establish initial plant breeding nurseries from plant collections
Summer-Fall, 1999:	Evaluate nurseries for important agronomic traits
Spring-Fall, 2000:	Identify individuals for further genetic evaluation and seed production
Spring 2001:	Establish plant breeding nurseries of half-sib families for estimating heritabilities and genetic variability in each species for important agronomic traits
Summer-Fall 2001:	Continue evaluation of collection nurseries, evaluate half-sib family nurseries, perform selection and produce populations from the superior families
Spring 2001:	Plant seed from the first cycle of selection to continue plant breeding program
Summer-Fall 2001:	Continue evaluation of half-sib families and evaluation of the first cycle of selection in Illinois bundleflower and false indigo

6. Budget requirements:

Category	Organization	Indigenous Legumes	In-Kind Support
Personnel:			
Student internship(s)	U of MN	$ 12,000	
Nancy Ehlke (faculty)	U of MN		$15,000
Greg Cuomo (faculty)	U of MN		$10,000
Technician: (0.5)	U of MN	$30,000	
Donn Vellekson (technician)	U of MN		$5,000
Staff: Audrey Arner (0.5)	LSP	$34,000	
Research Assistantship (1)	U of MN	$40,000	
Total:		$116,000	$30,000

7. Cooperators:

Scientists: Dr. Nancy Ehlke, Professor, U of MN, Dept. of Agronomy and Plant Genetics
Dr. Greg Cuomo, Assistant Professor, U of MN, West Central Experiment Station
Mr. Lee De Haan, Graduate Research Assistant, U of MN, Dept. of Agronomy an Plant Genetics

Non-profits: Ms. Audrey Arner, Western Minnesota Office of the Land Stewardship Project, Montevideo, MN. Ms. Arner has been involved with generating ideas and developing the proposal. She will be involved with the coordination of the on-farm trials in western Minnesota, for developing interactions among the producers, and for developing and implementing the outreach activities.

Producers: Ms. Jodi Dansingburg, Rt. 1, Box 121C, Rushford, MN 55971. Ms. Dansingburg will manage an on-farm research project with beef cattle. She will host field days and provide land and livestock resources for conducting replicated grazing studies on her farm.

Mr. Richard Handeen, Moonstone Farm, 9060 40th St. SW, Montevideo, MN 56265. Mr. Handeen will manage an on-farm research project with beef cattle. He will host field days and provide land and livestock resources for conducting replicated grazing studies on his farm.

Mr. Don Struxness, 14015 Hwy. 40 NW, Milan, MN 56262. Mr. Struxness will manage an on-farm research project with beef cattle. He will host field days and provide land and livestock resources for conducting replicated grazing studies on his farm.

8. References:

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Lueschen, W.E. 1997. Unpublished data collected in 1997 from the native perennial legume nursery on the University of Minnesota Saint Paul Experiment Station. The nursery was established in 1995.

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Towne, E.G., and A.K. Knapp. 1996. Biomass and density responses in tallgrass prairie legumes to annual fire and topographic position. *American Journal of Botany* 83:175-179.

Appendix of Data: July 1, 2001
Diversifying Agriculture for Environmental, Economic, and Social Benefits

Result 1. Cover crops for Northwestern Minnesota

- Tables 1-16
- Manuscript: Wiersma et. al. 2001. Intercropping Legumes in Hard Red Spring Wheat to Reduce Fusarium Head Blight. Agronomy J. (in review)

Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 1. Reducing the loss of nitrate-N from subsurface tile drainage

- Figures 1-3
- Table 1

Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 2. To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment I. Alternative crops seeded into corn

- Tables 1-6
- Figure 1

Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 2. To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment II. Cereal rye cover crop variety evaluation

- Tables 1-3
- Figure 1

Result 2. Cover crops for southern Minnesota

II. Evaluating legumes intercropped in small grains

- Tables 1-13

Result 2. Cover crops for southern Minnesota

III. Kura clover as a perennial living mulch

- Tables 1-4
- Kura clover living mulch information fact sheet

Result 3. Agroforestry

- Table 1-2
- Hazelnut Information leaflet

Result 4. Indigenous native perennial legumes

- Tables 1-3
- Manuscript 1. Dehaan et al., 2001. Evaluation of diversity among and within accessions of Illinois bundleflower. Crop Sci. (in review)
- Manuscript 2. Dehaan et al., 2001. Evaluation of diversity among accessions of false indigo. Crop Sci. (in review)

Result 1. Cover crops for Northwestern Minnesota

- **Tables 1-16**
- **Manuscript: Wiersma et. al. 2001. Intercropping Legumes in Hard Red Spring Wheat to Reduce Fusarium Head Blight. Agronomy J. (in review)**

Result 1.

Objective 1. Identify hairy vetch ecotypes that positively influence crop productivity.

Table 1. Development and dry matter production of four hairy vetch ecotypes established in wheat stubble and in standing soybeans on August 28, 1999 and on August 15, 2000 in Madison, MN.

Seeding Technique	Target vetch population (plants/ a)	First planting: Vetch population (live plants / a) 11/1/99	First planting: Vetch population (live plants / a) 5/15/00	First planting: Vetch dry matter lb/ acre 11/1/99	First planting: Vetch dry matter lb/ acre 5/15/00	Second planting: Vetch population (live plants / a) 11/1/00	Second planting: Vetch population (live plants / a) 5/15/01	Second planting: Vetch dry matter lb/ acre 11/1/00	Second planting: Vetch dry matter lb/ acre 5/15/01
Disked wheat stubble									
NW Minnesota ecotype	135000	34709	3178	123	83	47742	28575	151	43
SW Minnesota ecotype	135000	36734	3673	107	77	54363	29621	118	43
Nebraska ecotype	135000	28042	2565	89	69	38681	26484	96	39
California ecotype(Lana)	135000	27061	0	86	0	36590	19515	62	25
mean		31637	2354	101	57	44344	26049	107	38
LSD(0.10)		*5345*	*1546*	*ns*	*43*	*5123*	*4598*	*53*	*24*
Standing soybeans									
NW Minnesota ecotype	135000	20266	3753	99	85	51575	30666	101	33
SW Minnesota ecotype	135000	28779	2648	90	80	53181	33106	93	54
Nebraska ecotype	135000	16434	3175	83	83	42515	23697	85	36
California ecotype(Lana)	135000	22025	0	75	0	43908	17772	56	15
mean		21876	2394	87	62	47795	26310	84	35
LSD(0.10)		*5345*	*1546*	*ns*	*43*	*5123*	*4598*	*53*	*24*
Seeding technique LSD(0.05)		7356	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Methods.

First planting:

Vetch was broadcast into disked wheat stubble on August 28, 1999.

Vetch was broadcast into standing soybeans on August 28, 1999.

Vetch was innoculated with appropriate rhizobia and seeded at a rate of 15 lb/acre.

Second planting:

Vetch was broadcast into disked flax stubble on August 15, 2000.

Vetch was broadcast into standing soybeans on August 15, 2000.

Vetch was innoculated with appropriate rhizobia and seeded at a rate of 15 lb/acre.

Location : Fernholz farm, Madison, MN.

Objective 2. Evaluation of perennial legume cover systems for small grain production.

Table 2. Cultivars, seeding rates and desired stands of wheat and three interseeded legumes in Crookston, Morris, and Roseau, MN. 1999-2000.

Species	Common Name	Cultivar	Seeding rate	Desired stand
			(lbs a^{-1})	(plants ft^{-2})
Triticum aestivum	Wheat	Hamer	75	23
Medicago sativa	Alfalfa	Vernal	6	29
Vicia villosa	Hairy vetch	Local ecotype*	10	5
Trifolium pratense	Red clover	Marathon	5	30

*Local ecotype obtained from J. Derosier of Red Lake Falls, MN.

Table 3. Stand counts and plant height of wheat and three interseeded legumes. Average of three locations. 1999-2000.

	Stand				Plant height	
interseeded legume	initial legume	initial wheat	harvest legume	harvest wheat	Legume	Wheat
	----------------(plants ft^{-2})----------------				(inches)	
No Cover	0	27	0	26	0	32
Alfalfa	12	27	15	26	10	32
Hairy vetch	4	27	5	26	24	32
Red clover	11	28	15	26	9	31
LSD.05	4	ns	8	ns	8	ns

Table 4. Biomass of three interseeded legumes and grain yield and quality of spring wheat. Average of three locations. 1999-2000.

Interseeded	Spring wheat			Legume dry biomass	
Legume	Yield	Test weight	Protein	Harvest	Plowdown
	(bu a^{-1})	(lbs bu^{-1})	(%)	----------(lbs a^{-1})---------	
No legume	45.0	56.3	14.5	0	0
Alfalfa	42.7	55.9	14.6	382	944
Vetch	41.0	54.9	14.5	1196	1288
Red Clover	42.0	55.8	14.6	683	1197
LSD.05	3.8	1.2	ns	833	833

Table 5. Influence of interseeded legumes on field severity and visual kernel damage by Fusarium head blight across three environments. Crookston, Morris, and Roseau, MN. 1999-2000.

Interseeded Legume	Fusarium head blight field severity	Fusarium head blight damaged kernels
	(%)	(%)
No legume	5.0	2.5
Alfalfa	3.8	1.9
Vetch	2.6	1.5
Red Clover	2.1	2.0
LSD.05	ns	ns

Objective 3. Evaluation of the productivity of alternative rotations with forage seed species.

Table 6. Yield of soybean, wheat, and flax interseeded with three perennial grasses and legumes, Roseau, Minnesota, 1999-2002.

	Soybean			Wheat			Flax		
Interseeded crop	1999_A	2000_B	2001_C	1999_A	2000_B	2001_C	1999_A	2000_B	2001_C
	(bu/a)								
Perennial Ryegrass	23.6	33.4	*na*	31.6	49.7	*nd*	5.0	16.3	*na*
Birdsfoot Trefoil	30.2	39.2	*na*	32.9	50.1	*na*	14.0	20.0	*na*
Red Clover	30.0	39.0	*na*	32.5	50.4	*na*	16.0	21.8	*na*
none	30.2	39.4	*na*	35.4	51.0	*na*	23.5	28.6	*na*
LSD.05	3.1	3.9		4.1	5.7		3.5	3.1	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 7. Seed yield of three perennial grasses and legumes in the year following establishment.

	Perennial ryegrass		Birdsfoot trefoil		Red Clover		Wheat check	
Previous year crop.	2000_A	2001_B	2000	2001_B	2000_A	2001_B	2000_A	2001_B
	(lb/a)							
Soybean	852	*na*	135	*na*	248	*na*	3412	*na*
Wheat	825	*na*	169	*na*	218	*na*	3003	*na*
Flax	886	*na*	207	*na*	223	*na*	3010	*na*
No Crop	853	*na*	210	*na*	279	*na*	3246	*na*
LSD.05	33		17		25		228	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 8. Stand of interseeded perennial forage species in the season following establishment (2nd planting). Roseau, MN. 2001.

Previous year crop.	Perennial ryegrass	Birdsfoot trefoil	Red Clover
	% of target stand		
Soybean	35	25	80
Wheat	66	50	96
Flax	12	94	86
No Crop	7	71	93
LSD.05	23	24	13

Table 9. Weed suppression in evaluated rotations in 1st and 2nd plantings in Roseau, MN.

Crop 1	interseeded crop	Herbicides applied	% Weed biomass suppression Broadleaf 1st planting	Broadleaf 2nd planting	Grass 1st planting	Grass 2nd planting	comments
Soybean	none	glyphosate(.5 lb a^{-1})	91	92	98	98	
Soybean	Perennial ryegrass	bentazon(.5 lb a^{-1})+quizalofop (.06 lb a^{-1})	80	73	99	95	lambsquarter and pigweed suppressed /not killed
Soybean	Birdsfoot trefoil	glyphosate(.5 lb a^{-1})	92	92	97	95	
Soybean	Red clover	imazethapyr (.06 lb a^{-1})	79	95	91	95	poor lambsquarter control in 1st planting
Wheat	none	fenoxaprop (.062 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	84	88	98	99	
Wheat	Perennial ryegrass	fenoxaprop (.062 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	87	93	88	95	
Wheat	Birdsfoot trefoil	fenoxaprop (.062 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	87	88	87	88	
Wheat	Red clover	fenoxaprop (.062 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	89	91	95	95	
Flax	none	quizalofop (.06 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	85	89	95	90	pigweed suppressed /not killed
Flax	Perennial ryegrass	quizalofop (.06 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	82	91	87	91	pigweed suppressed /not killed
Flax	Birdsfoot trefoil	quizalofop (.06 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	87	90	87	90	pigweed suppressed /not killed
Flax	Red clover	quizalofop (.06 lb a^{-1}) + bromoxynil (.25 lb a^{-1}).	85	87	92	95	pigweed suppressed /not killed
None	Perennial ryegrass	bentazon(.5 lb a^{-1})+quizalofop (.06 lb a^{-1})	83	91	95	92	lambsquarter and pigweed suppressed /not killed
None	Birdsfoot trefoil	glyphosate(.5 lb a^{-1})	92	94	92	94	
None	Red clover	imazethapyr (.06 lb a^{-1})	80	78	90	95	poor lambsquarter control
		LSD.05	11	15	9	10	

Table 10. Mean weed densities in plot area prior to treatment (number per m^2). Magnusson Research Farm, Roseau, MN. 1999-2001.

	Date	Pigweed	Lambsquarter	Smartweed	Wild Mustard	W. Buckwheat	Green Foxtail
1st planting	15-Jun-99	4.4	2.1	4.5	8.6	0.4	4.3
2nd planting	18-Jun-00	3.3	2.3	3.0	0.6	0.2	1.8

Table 11. Influence of interseeded forages on crop height.

Interseeded Forage	Soybean 1999_A	Soybean 2000_B	Soybean 2001_C	Wheat 1999_A	Wheat 2000_B	Wheat 2001_C	Flax 1999_A	Flax 2000_B	Flax 2001_C
	crop height (cm)								
Perennial Ryegrass	71	71	*na*	86	91	*na*	58	52	*na*
Birdsfoot Trefoil	78	71	*na*	85	92	*na*	57	54	*na*
Red Clover	77	69	*na*	87	90	*na*	61	53	*na*
none	76	68	*na*	88	90	*na*	62	53	*na*
LSD.05	4	5		3	3		3	3	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 12. Influence of soybean , wheat , and flax on height of three interseeded cover crops.

Row crop	Perennial ryegrass Sep-99$_A$	Sep-00$_B$	Sep-00$_C$	Birdsfoot trefoil Sep-99$_A$	Sep-00$_B$	Sep-00$_C$	Red clover Sep-99$_A$	Sep-00$_B$	Sep-00$_C$
	----------cover height (cm)----------								
Soybean	36	37	*na*	30	33	*na*	32	36	*na*
Wheat	40	41	*na*	34	36	*na*	40	42	*na*
Flax	38	33	*na*	25	23	*na*	35	29	*na*
No crop	40	33	*na*	38	20	*na*	28	38	*na*
LSD .05	4	4		8	4		5	4	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 13. Fall dry matter production of perennial ryegrass, birdsfoot trefoil, and red clover following grain harvest at Roseau, MN, 1999-2000.

Row crop	Perennial ryegrass Nov-99$_A$	Nov-00$_B$	Nov-00$_C$	Birdsfoot trefoil Nov-99$_A$	Nov-00$_B$	Nov-00$_C$	Red clover Nov-99$_A$	Nov-00$_B$	Nov-00$_C$
	----------dry matter (lb/a)----------								
Soybean	1756	1345	*na*	185	222	*na*	524	637	*na*
Wheat	1687	1824	*na*	370	422	*na*	750	1133	*na*
Flax	1054	967	*na*	271	288	*na*	1099	953	*na*
No crop	1147	1198	*na*	494	252	*na*	1126	1373	*na*
LSD .05	163	211		87	103		168	166	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 14. Spring regrowth of perennial ryegrass, birdsfoot trefoil, and red clover at Roseau, MN, 1999-2000.

Row crop	Perennial ryegrass May-00$_A$	May-01$_B$	May-02$_C$	Birdsfoot trefoil May-00$_A$	May-01$_B$	May-02$_C$	Red clover May-00$_A$	May-01$_B$	May-02$_C$
	----------dry matter (lb/a)----------								
Soybean	1653	666	*na*	1386	905	*na*	1624	2806	*na*
Wheat	2085	1091	*na*	2772	1753	*na*	2326	3346	*na*
Flax	2008	256	*na*	2034	3078	*na*	3408	3022	*na*
No crop	2150	192	*na*	3708	2385	*na*	3489	3281	*na*
LSD .05	388	355		388	355		388	355	

A. 1st planting (1999-2000)
B. 2nd planting (2000-2001)
C. 3rd planting (2001-2002)

Table 15. Projected market value of seed produced in several annual/perennial crop rotations.

Annual crop	Interseeded perennial crop	Second Year Crop	2000A Market value**
			($ /a)
Soybean	Perennial ryegrass	Perennial ryegrass	456
Soybean	Birdsfoot trefoil	Birdsfoot trefoil	336
Soybean	Red clover	Red clover	394
Soybean	None	Wheat	352
Wheat	Perennial ryegrass	Perennial ryegrass	447
Wheat	Birdsfoot trefoil	Birdsfoot trefoil	354
Wheat	Red clover	Red clover	334
Wheat	None	Wheat	307
Flax	Perennial ryegrass	Perennial ryegrass	378
Flax	Birdsfoot trefoil	Birdsfoot trefoil	357
Flax	Red clover	Red clover	300
Flax	None	Wheat	274
None	Perennial ryegrass	Perennial ryegrass	341
None	Birdsfoot trefoil	Birdsfoot trefoil	294
None	Red clover	Red clover	279
None	None	Wheat	195

**calculations based on grain and seed prices on 11/20/00.

Table 16. Materials, varieties and seeding rates:

1st planting (1999)	Seeding date: May 15, 1999	
crop	variety	seed rate
Wheat	Russ	80 lb/a
Flax	Norlin	40 lb/a
Soybean	DeKalb RR gp 0.3	50 lb/a
Red Clover	Marathon	10 lb/a
Birdsfoot trefoil	Roseau	9 lb/a
Perennial ryegrass	P 1 (U of MN experimental)	12 lb/a
2nd planting (2000)	Seeding date: May 19, 2000	
Wheat	Hamer	80 lb/a
Flax	Norlin	40 lb/a
Soybean	DeKalb RR gp 0.3	50 lb/a
Red Clover	Marathon	10 lb/a
Birdsfoot trefoil	Roseau	9 lb/a
Perennial ryegrass	P 1 (U of MN experimental)	12 lb/a
3rd planting (2001)	Seeding date: June 17, 2001	
Wheat	Alsen	80 lb/a
Flax	Norlin	40 lb/a
Soybean	Ramy RRgp00.9	50 lb/a
Canola	Hyola(RR)	5 lb/a
Red Clover	Marathon	10 lb/a
Birdsfoot trefoil	Roseau	9 lb/a
Perennial ryegrass	P 1 (U of MN experimental)	12 lb/a

20-10-10 fertilizer applied over plot area at a rate of 500 lb per acre.

Version 1: 1 July 2001

Intercropping Legumes in Hard Red Spring Wheat to Reduce Fusarium Head Blight.

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Abstract:

-- Not written yet --

Introduction:

The value of legumes in crop rotations has been recognized for centuries. The principal benefit attributed to legumes in crop rotations is their contribution of mineral nitrogen to the soil (Badaruddin et al, 1989; Baldock et al, 1981). In addition to fertility benefits, legume covers provide soil protection from rain impact, reducing runoff by improving water infiltration rates. Organic matter provided by legume covers improves soil structure and increases its stability (Biederbeck, 1994).

Due to the availability of low cost nitrogen, the use of legumes in rotational systems for green manure purposes has greatly decreased (Badaruddin, 1990). Current farm economics discourage the use of a fallow year to produce a green manure crop. However, recent findings have shown that it may be possible to grow a legume crop simultaneously with a grain crop (Kandel et al, 1997; Hesterman et al, 1992; Moynihan, 1996) thereby eliminating the need for a fallow year in the rotation. By intercropping legumes into existing crops, some of the benefits of having legumes in the rotation can be achieved without the loss of cropping year. Some intercropped legume species receive enough light early in the season to successfully establish before the primary crop canopy intercepts all available sunlight. The legumes covers are then in place to make use of light available late in the season when the primary crop begins to senesce (Fukai, 1993).

McMullen et al. (1997) described how Fusarium head blight caused by *Fusarium graminearum* has had a devastating impact on wheat and barley production in the Upper Midwest since the early nineties. Economic loss estimates range between $1.3 billion and $3.0 billion in the United States during that period (Johnson et al., 1997; Windels, 2000). Parry et al. (1995) provided a good review of the possible control measurements and their effectiveness, including genetic resistance, cultural control techniques, and chemical and biological control but did not mention intercropping as a possible solution. However, Bannon and Cooke (1998) found that, when winter wheat was interseeded with clover, the clover significantly reduced the dispersal of *Septoria tritici* spores in the horizontal direction by 33%. The clover also reduced the vertical movement of spores from infected leaves at the base of the wheat plants by an average of 63%. Like *Septoria tritici, Fusarium graminearum* is a residue born disease. Hence a potential benefit of intercropping legumes in small grains is a reduction in the incidence and severity of Fusarium head blight. Legumes interseeded with wheat will cover the soil before wheat reaches anthesis. This soil cover may provide a barrier to infection of developing wheat by inoculum of *Fusarium graminearum* from plant residue. Before the advent of crop protection chemicals, crop rotation and diversification were standard interventions for reduce insects, diseases, and weeds. By adding new innovations to these historically proven methods, it may be possible to address crop pest problems that are currently impacting agriculture (Liebman, 1988).

The objectives of this study are to evaluate if intercropping spring wheat with selected legumes will result in:

1) A reduction of Fusarium head blight;
2) A similar grain yield compared to spring wheat grown in monoculture;
3) A legume crop that can be used as a green manure crop.

Materials & Methods:

In 1999 a two-year study was initiated at Morris, Crookston and Roseau, MN. Using a Latin Square, the hard red spring wheat (*Triticum aestivum*) cultivar 'Hamer', rated as susceptible to Fusarium head blight, was either intercropped with alfalfa (*Medicago sativa*), hairy vetch (*Vicia villosa*) or red clover (*Trifolium pratense*) or planted in monoculture and replicated four times at each location. The seeding rates and desired stands are listed in Table 1. The wheat was planted using a double-disk grain drill at all three locations. In Morris the legumes were planted with the grain drill when planting the wheat using a grass seed attachment. At the other two locations, the legumes were spread and raked in by hand prior to planting the wheat. Plots measured 24' by 48'.

To control both grasses and broadleaf weeds trifluralin (Treflan) at 0.75 lbs AI acre^{-1}was applied pre-plant and incorporated in the seedbed. Additional broadleaf weed control was provided with one application of bromoxynil (Buctril) at 0.25 lbs AI acre^{-1} once the legumes had reached the second trifoliate. To provide a source of inoculum for *Fusarium graminearum*, the previous crop in Morris, MN was corn. In Roseau, MN, wheat was used as a previous crop. In Crookston, MN, artificial inoculum of infected corn seed and a misting system was used to promote disease development.

The data collected included stand counts for both wheat and the legume at the 2 to 3 leaf stage of the spring wheat and again a just before grain harvest. In addition, plant height of the spring wheat and the legumes were measured just before grain harvest. Field severity of Fusarium head blight was estimated by multiplying incidence and severity estimates on a plot mean basis approximately 21 days after anthesis. A percent visually scab damaged kernels or VSK score was taken at harvest on a representative grain sample. Grain yield, testweight and grain protein were determined for wheat by harvesting the center 5 feet of each plot. Biomass production of the legumes was estimated at grain harvest and a second time in late fall by hand cutting a one square yard subplot within each plot.

In 1999 plots in Roseau sustained heavy rains and the fourth replication was lost due to flooding. Similarly, the experiment in Crookston in 1999 was lost after the initial stand counts were taken. In 2000, the plots in Morris and Crookston suffered drought stress early in the season and continued drought in Morris during anthesis and grain fill resulted in no disease pressure. Analysis of variance was computed for all traits across environments or single environment if appropriate. Because whole replications were lost in one of the locations, the Latin Square design used was no longer balanced. Consequently the analysis of variance was calculated by only using replications instead of the rows and columns used in the Latin Square design. All sources of variation, except the treatments were considered random. Differences amongst treatments were tested with the appropriate F-test. Least significant differences were calculated if treatments differed statistically.

Results and Discussion

The average initial stands of wheat and the legumes as well as the stands just prior to harvest are summarized in Table 2. Plant height of the wheat and the legumes are summarized in Table 2. No significant difference was found between treatments for the initial stand and the stand at harvest of wheat, indicating that the legumes did not out-compete wheat. In comparison to the targeted stand some interesting results were obtained. The realized stands of the legumes were higher than the targeted stands. Possible explanations for this discrepancy are; 1) a possible wrong calibration of the grass seed unit on the drill used in Morris and 2) an uneven distribution of the legume seed within plots when seeding by hand and subsequently preferential sampling for areas in the plots when counting stands. The later must certainly have occurred has the stands of the legumes were very erratic and unevenly distributed within the plots in both Crookston, and Roseau. The C.V values observed in both Crookston and Roseau, varying between 60 and 200 for the different treatments that included a legume as compared to C.V. values of 20 to 30 in Morris support this. No significant difference was observed for plant height of the wheat between the treatments. Hairy vetch was significantly taller than either alfalfa or clover and approached the top of the canopy at harvest (Table 2). This posed a problem when combining the wheat. For this reason, hairy vetch is not a good candidate for intercropping with spring wheat.

Grain yield and biomass results are summarized in Table 3. Interseeding legumes tended to reduce grain yield, with the grain yield of wheat interseeded with hairy vetch being significantly less than the monocrop of wheat. Testweight also was significantly less for the wheat when intercropped with hairy vetch and tended to be lower with the other two legumes when compared to the monocrop of spring wheat. No significant difference was observed for grain protein content. At the time of grain harvest, the above ground biomass of the three legumes was from nearly 400 lbs acre-1 for the alfalfa to almost 1200 lbs acre for the hairy vetch (Table 3). Again, stands were generally very spotty and uneven and collecting meaningful samples was difficult. Alfalfa and red clover doubled their biomass from grain harvest to the first killing frost. Hairy vetch, being cut during grain harvest because of it's plant height, recovered generally very well and produced the most biomass for plow down as a green manure at 1288 lbs acre-1. All three legumes averaged around half a ton per acre of green manure at plow down.

The legumes provided no significant reduction in both field severity and VSK score (Table 4). However, the average scores of all three legumes tended to be lower. Overall disease pressure was light (even under misted conditions in Crookston) and combined with the uneven legume stands this experiment is inconclusive to whether intercropping legumes can reduce the risk of Fusarium Head Blight

Conclusion

With the difficulties that were experienced at two of the three locations in establishing a uniform and even stand of the legume, the results are inconclusive to whether intercropping wheat with any of the three legumes provides a reduction in incidence and severity of Fusarium head blight. Grain yield tended to be less when spring wheat was intercropped with wheat. The seeding rate for spring wheat was less than needed to attain recommended plant stand of 28 to 30 plants per square foot. The reason for this was to allow for a better environment for the legumes to establish themselves before the spring wheat canopy would close. This lower seeding rate used for the spring wheat is likely to increase the difference between the intercropped spring wheat and a monocrop of wheat if the later is planted at a recommended seeding rate. Of the three legumes used in this experiment, hairy vetch is not suitable for intercropping with spring wheat as it grows too tall when the spring wheat crops matures, hindering in the grain harvest. All three legumes grew after the spring wheat was harvested and provided a small green manure crop at the end of the season.

Finally, weed control was problematic as the combination of pre-plant incorporated trifluralin and/or post-emergence bromoxynil proofed inadequate for effective pigweed control (no data presented). Thus, in summary, intercropping wheat to reduce Fusarium head blight and provide a cost-effective means to produce a green manure crop does not appears to be a viable alternative to the standard practices currently used.

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Table 1 - Cultivars, seeding rates and desired stands of three legumes and wheat interseeded in three locations in Minnesota in 1999 and 2000.

Species	Common name	Cultivar	Seeding Rate (lbs/acre)	Desired Stand (plants/ft^2)
Triticum aestivum	Wheat	Hamer	75	23
Medicago sativa	Alfalfa	Vernal	6	6
Vicia villosa	Hairy vetch	Local Ecotype*	10	3
Trifolium pratense	Red clover	Marathon	5	5

* Local ecotype obtained from J. Derosier of Red Lake Falls, MN.

Table 2 - Stand counts and plant height of wheat and three legumes when intercropping three legumes and spring wheat in Minnesota.

Treatment	*Stand*				*Plant Height*	
	Initial Legume	*Initial Wheat*	*Harvest Legume*	*Harvest Wheat*	*Legume*	*Wheat*
	(# ft^2)				(inches)	
No legume	0.0	26.9	0.0	25.7	0.0	31.5
Alfalfa	12.2	27.1	15.4	25.9	9.6	31.7
Hairy Vetch	3.5	27.1	5.2	25.9	24.4	31.6
Red Clover	11.3	27.5	14.8	25.9	8.5	31.2
LSD (0.05)	4.4	NS	7.8	NS	7.8	NS

Table 3 - Biomass of three legumes and grain yield and quality of spring wheat when intercropping three legumes and spring wheat in Minnesota.

Treatment	*Spring Wheat*			*Legume*	
	Yield	Testweight	Protein	Harvest	Plowdown
No legume	45.0	56.3	14.5	0	0
Alfalfa	42.7	55.9	14.6	382	944
Hairy Vetch	41.0	54.9	14.5	1196	1288
Red Clover	42.0	55.8	14.6	683	1197
LSD (0.05)	3.8	1.2	NS	833	

Table 4. Field severity for Fusarium Head Blight and percent visual scab damaged kernels across three environments in Minnesota when interseeding three legumes in wheat.

Treatment	*FHB Field Severity*	*VSK*
	---------(%)--------	
No Legume	5.0	2.5
Alfalfa	3.8	1.9
Vetch	2.6	1.5
Clover	2.1	2.0
LSD (5%)	NS	NS

Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 1. Reducing the loss of nitrate-N from subsurface tile drainage

- Figures 1-3
- Table 1

Result 2. Objective 1.

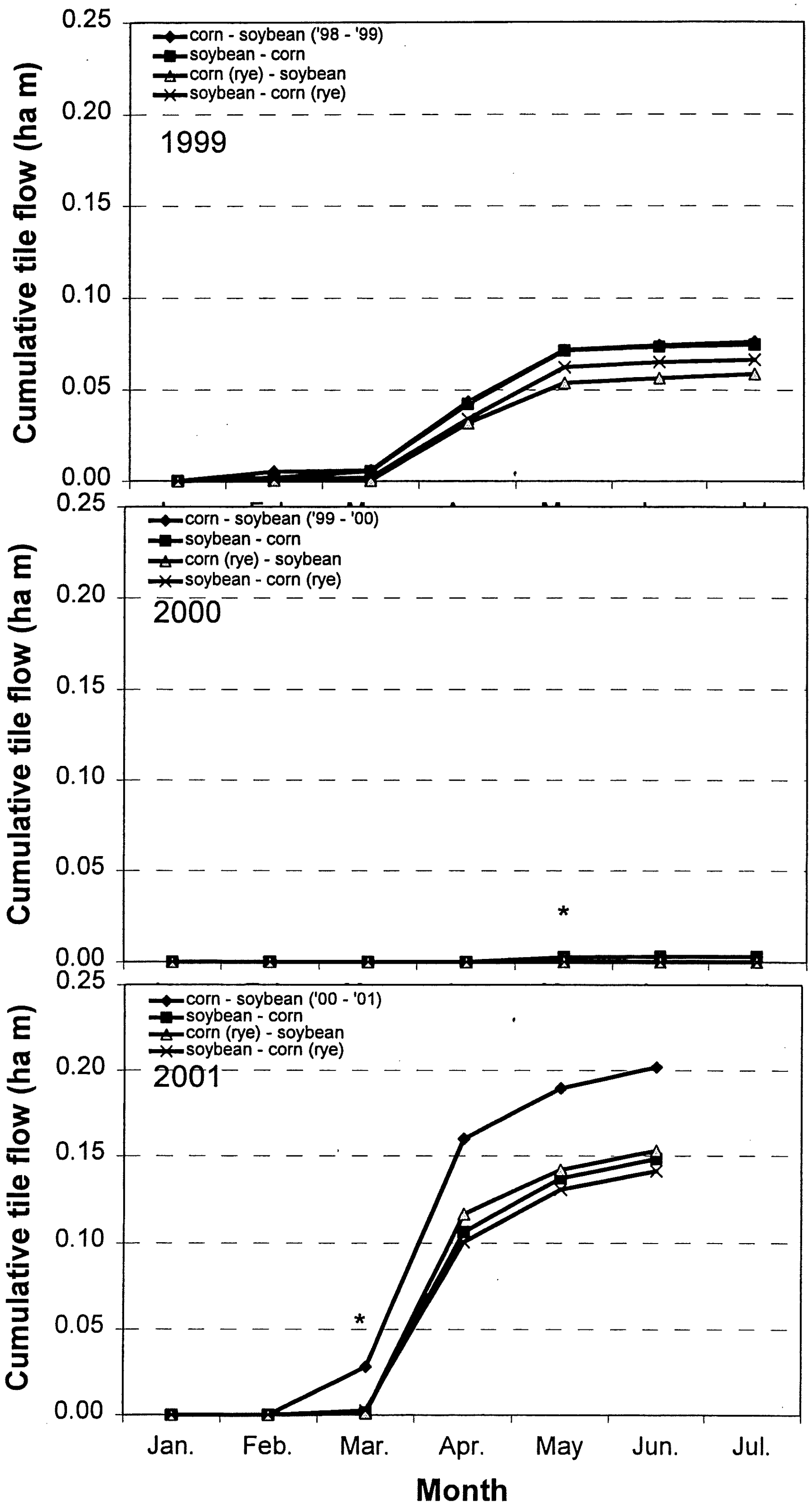


Fig. 1. Cumulative tile flow from experimental plots at Lamberton, during the 3-year period from 1999-2001. Asterisk denotes significant difference *(p = 0.05).*

Result 2. Objective 1.

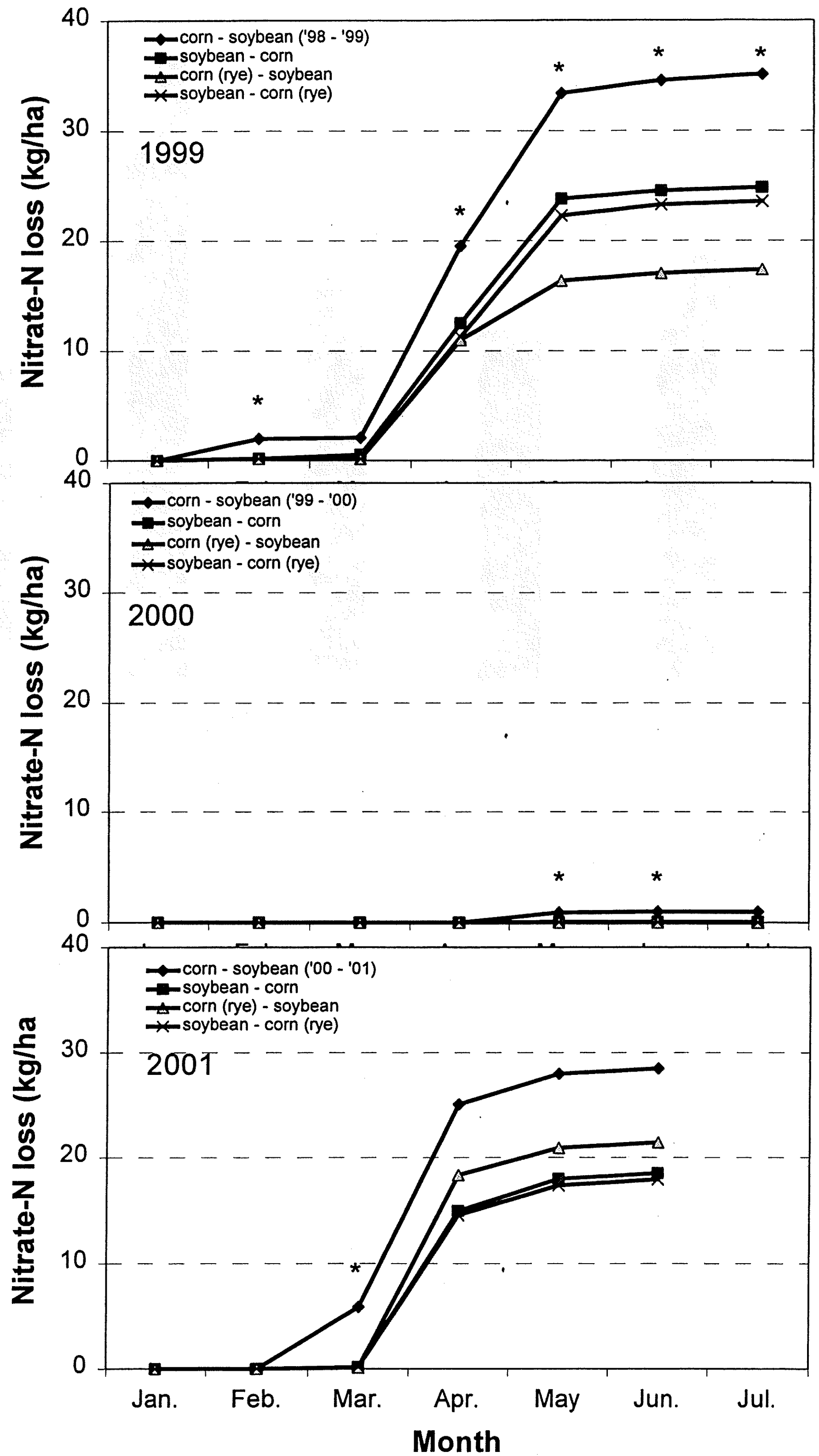


Fig. 2. Cumulative nitrate-N loading from experimental plots at Lamberton, during the 3-year period from 1999-2001. Asterisk denotes significant difference *(p = 0.05)*.

Result 2. Objective 1.

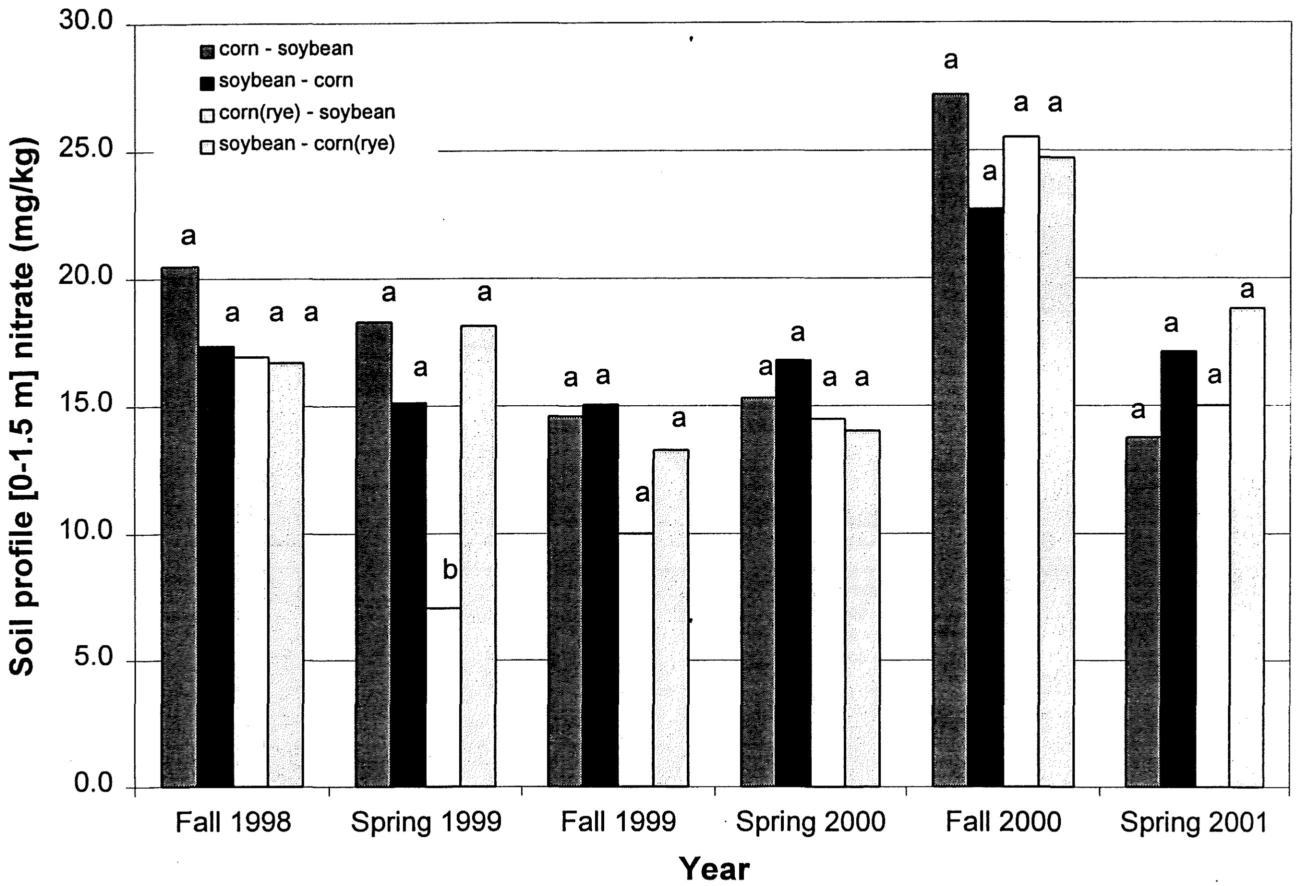


Fig. 3. Total soil nitrate-N in a 1.52 m soil profile from experimental plots at Lamberton during a 4-year period (1998-2001).

Mean corn and soybean yield as affected by cropping system and rye biomass during a 3 year period (1998-01) in Minnesota.

	Cropping system				
	Corn - soybean	$Corn_{rye}$ - soybean	Soybean-corn	Soybean - $corn_{rye}$	Rye biomass
	Mg/ha				
1998-99	2.7 a	2.7 a	10.0 a	9.6 a	2.74 ± 0.18†
1999-00	3.5 a	3.4 a	9.8 a	9.7 a	0.95 ± 0.08†
2000-01					0.61 ± 0.04†

Values followed by a different letter are significant (p = 0.05). † Standard error of mean.

Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 2. To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment I. Alternative crops seeded into corn

- Tables 1-6
- Figure 1

Experiment I. Alternative crops seeded into corn

Farm sites were selected on the basis of three criteria: farmer interest in the experiment's objectives, suitable slope in a field planted to corn, and weed management practices compatible with relay interseeding of the cover crops into standing corn. The farms selected and the slope of each experimental site are shown in Table 1. The number of interseed/planting date treatments included in the experiment was constrained by the limited area of suitable slope available at each site. All sites but the Halter farm included six interseed/planting date treatments: annual ryegrass after second cultivation, red clover after second cultivation, annual ryegrass at tasseling, oat at tasseling, winter rye at tasseling, and no interseed. The Halter experiment omitted two treatments: annual ryegrass at tasseling and oat at tasseling. The interseed/planting date treatments were established at each of the three landscape positions at all five sites.

Actual planting dates are listed in Table 2. Of the three species planted at corn tasseling, only annual ryegrass emerged. The failure of the relatively large-seeded rye and oat treatments to establish at tasseling was probably due to the lack of rainfall (<1 inch) in the two-week period following tasseling, coupled with poor seed-to-soil contact (treatments were sown by hand and only roughly incorporated with a hoe). All rye and oat treatments were subsequently replanted (Table 2).

Corn yield data were collected at all but the Southwest Research and Outreach Center (SWROC) site. Corn yield was unaffected by treatment at the Batalden site (data not shown). At the Halter site, corn yield was unaffected by landscape position, but plots interseeded with red clover after second cultivation had a lower yield than those without an interseed treatment (Table 3). At the Coulter and Moody sites, interseed treatment had no effect on corn yield, but plots at the foot slope had higher yields than those at the crest or linear slope landscape positions (Table 4).

Aboveground biomass accumulation of the interseed treatments was determined at all sites after corn harvest (Table 5). Annual ryegrass planted after second cultivation consistently accumulated more biomass than the other interseed/planting date treatments at all sites except at the Batalden site, where winter rye biomass accumulation was equal to that of the early ryegrass treatment. Drymatter accumulation of both the early and late ryegrass treatments and the winter rye treatment tended to be higher at the foot slope than at the linear slope and crest positions across the sites. The effect of landscape position on red clover biomass accumulation varied from site to site, while the oat treatment, which had the lowest biomass accumulation of the interseed treatments at the SWROC, Coulter, and Moody sites, appeared unaffected by landscape position. A heavy foxtail infestation at the Batalden site (which was the only site under organic management) was probably responsible for the consistently lower biomass accumulation of all interseed treatments at this site.

Fall soil samples were collected from all but the Batalden site, where plots were obliterated by fall tillage. Soil sampling at the other sites was impeded by snowfall and wet weather; consequently, soil samples were only collected at the footslope positions in each experiment. Soil samples were taken to a depth of 4 feet (1.2m) at one-foot increments and analyzed for nitrate-N. Results of the soil profile analysis for nitrate-N for the four sites are shown in Figure 1. Statistical analysis showed no significant differences in nitrate in the soil profile between cover crop treatments. The Coulter and Halter sites showed the expected trend, i.e., the interseed treatments, particularly the earlier-planted treatments, appear to show slight reductions in nitrate-N in comparison to the no cover crop treatment. However, this trend is not apparent at either the Moody or the SWROC sites. The consistently lower nitrate values at the Moody site may be due to the relatively steep slope at this site (10%), which could have caused increased surface water runoff to the foot slope position, resulting in increased nitrate leaching. Observations of sediment loss from the back slope position and redeposition at the foot slope of the Moody site support this hypothesis.

The lack of significant nitrate reduction in the fall soil profile may be partially explained by the generally poor growth of all cover crop treatments at all sites in the 2000 season. For example, the highest winter rye biomass accumulation in these trials (0.1 Mg ha^{-1}) was half that attained in previous experimentation with rye interseeds in corn in Minnesota (Reicosky and Warnes, 1991). The poor growth of the interseeds is a likely result of the droughty conditions that prevailed in late summer and fall in the region, particularly in September when rainfall accumulation was over two inches below the 30-year average for the area.

Cover crop biomass accumulation was assessed again in mid-May 2001 for the two overwintering interseeds, red clover and winter rye (Table 6). Landscape position affected biomass accumulation only at the Coulter site, where biomass accumulation at the foot slope was more than twice that found at the summit and back slope locations. At both the Coulter and Moody sites winter rye biomass accumulation was greater than that of red clover. There was no difference in biomass accumulation between the two cover crops at the Halter or SWROC sites. Spring biomass accumulation was poor at all sites. The Coulter site did show an increase in biomass accumulation of the two cover crop species compared to fall biomass values: red clover biomass increased by almost 60% while winter rye biomass more than doubled (Tables 5 and 6). However, the spring biomass accumulation of winter rye at the Coulter site was less than a quarter of the spring aboveground biomass of rye in previous experiments in Minnesota (Reicosky and Warnes, 1991) and less than a tenth of that found in experiments with rye interseeding into corn in New York (Scott et al., 1987). Factors likely responsible for the generally poor spring regrowth of the overwintering cover crops at all sites include the poor establishment of the covers in the 2000 growing season and cool spring growing conditions (e.g., soil temperature at 1.6 cm depth remained 1.6 ° C lower in March and April than the 30-year average). A visual rating of crop residue in all plots at the Moody, Coulter, and SWROC sites (the Halter site was not surveyed) showed no differences between the winter-killed cover crop treatments and the no- cover-crop control treatment (data not shown), i.e., the fall biomass accumulation of these cover crops did not persist on the soil surface until time of planting of the subsequent crop

Table 1: Participating farms and slope of the experimental sites in the on-farm scavenger experiment

Farm	Slope
Moody	10% (east facing)
Coulter	6% (west facing)
Batalden	5% (west facing)
Halter	5% west, 2% north
SWROC[a]	6% (east facing)

[a]Southwest Research and Outreach Center of the University of Minnesota in Lamberton, MN.

Table 2: Planting dates of interseeds in the on-farm scavenger trials

	SWROC	Baltalden	Coulter	Halter	Moody
Annual ryegrass after second cultivation	7/4/00	7/13/00	7/4/00	7/17/00	7/6/00
Annual ryegrass at tasseling	7/20/00	7/28/00	7/18/00	--[a]	7/21/00
Red clover after second cultivation	7/4/00	7/13/00	7/4/00	7/17/00	7/6/00
Oat at Tasseling	7/20/00 Replanted 9/7/00	7/28/00 Replanted 9/7/00	7/18/00 Replanted 9/8/00	--	7/21/00 Replanted 9/8/00
Winter rye at tasseling	7/20/00 Replanted 9/6/00	7/28/00 Replanted 9/6/00	7/18/00 Replanted 9/6/00	7/28/00 Replanted 9/6/00	7/21/00 Replanted 9/6/00

[a]Treatment not included at this site.

Table 3: Corn yield ($Mg\ ha^{-1}$) at the Halter site

Interseed treatment	Yield*
Annual ryegrass planted following second cultivation	11.95a**
Red clover planted following second cultivation	11.22b
Winter rye planted in late August	11.61ab
No interseed	12.20a

*Means reported are adjusted for stand count using analysis of covariance.
** Within columns, means followed by the same letter are not significantly different at the 0.05 level.

Table 4: Corn yield ($Mg\ ha^{-1}$) at the Coulter and Moody Farms

	Farm site*	
Landscape position	Coulter	Moody
Crest	9.00b	8.10b
Slope	8.55b	6.36c
Foot	10.06a	9.29a

*Within columns, means followed by the same letter are not significantly different at the 0.05 level.

Table 5: Interseed fall biomass accumulation (g aboveground drymatter m^{-2}) in the on-farm scavenger study

	SWROC				Batalden				Coulter				Halter				Moody			
Interseed/ planting date	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean
Ryegrass early	4.8	16.3	13.4	11.5	1.6	2.3	2.5	2.1	9.4	10.1	52.9	27.0	7.8	13.9	18.6	13.4	10.1	4.5	11.2	8.9
Ryegrass late	2.5	5.4	12.0	6.6	0.1	0.5	0.7	0.5	0.9	1.2	11.0	4.4	--[a]	--	--	--	5.7	3.3	2.6	3.9
Red clover early	3.5	4.9	8.2	5.5	1.2	1.3	1.6	1.4	3.2	5.3	4.6	4.4	2.9	8.4	7.2	6.3	7.6	3.3	3.6	5.0
Oat late	1.1	2.0	1.7	1.6	0.3	0.5	0.6	0.5	1.9	2.5	1.4	2.0	--	--	--	--	1.4	1.4	1.1	1.3
Winter rye late	4.1	6.9	8.6	6.5	1.8	2.1	3.3	2.4	4.7	2.5	9.5	5.6	2.3	2.9	2.9	2.7	3.7	3.3	5.8	4.3
Mean	3.2	7.1	8.8	6.4	1.0	1.3	1.8	1.4	3.7	4.0	16.6	6.3	4.4	8.0	9.6	7.3	5.5	3.2	5.2	4.6
Statistical analysis[b]																				
Landscape position			**[c]				ns				**				ns			*		
Interseed/ planting date			****				**				****				***			****		
Position x interseed			*				ns				****				ns			**		

[a]Treatment not included at this site.

[b] Data were analyzed using the SAS® 'proc mixed' procedure to deal with the spatial correlation of the landscape position treatments in the experiments.

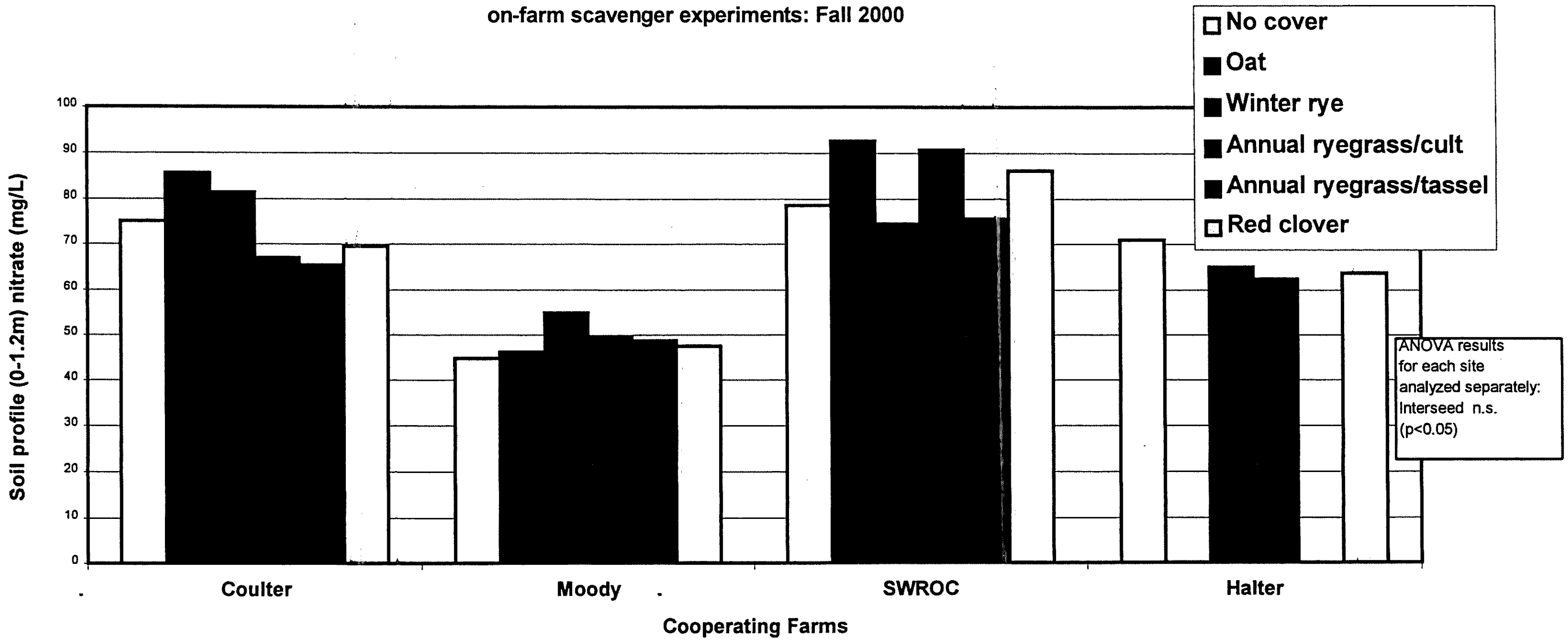
[c]Significance levels: ****,p<0.0001; ***,p<0.001; **, p<0.01; *, p<0.05; ns, not significant.

Table 6 Interseed spring biomass accumulation (g aboveground drymatter m^{-2}) in the on-farm scavenger study

	SWROC				Coulter				Halter				Moody			
Interseed	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean	Crest	Slope	Foot	Mean
Red clover	2.1	12.2	5.3	6.5	6.6	6.3	8.1	7.0	2.9	7.5	12.4	8.0	2.1	1.2	1.7	1.7
Winter rye	5.1	6.4	9.0	6.9	11.1	14.0	32.8	19.3	5.6	9.3	5.6	6.8	7.0	5.7	9.7	7.5
mean	3.6	9.3	7.2	6.7	8.8	10.1	20.5	13.1	4.4	8.4	9.0	7.4	4.6	3.4	5.7	4.6
Statistical Analysis[a]																
Landscape position	ns[b]				**				ns				ns			
Interseed	ns				*				ns				***			
Position x interseed	ns				ns				ns				ns			

[a]Data were analyzed using the SAS® 'proc mixed' procedure to deal with the spatial correlation of the landscape position treatments in the experiments.
[b]Significance levels: ***,p<0.001; **, p<0.01; *, p<0.05; ns, not significant.

Figure 1: Nitrate-N levels in the soil profile of on-farm scavenger experiments: Fall 2000



Result 2. Cover crops for southern Minnesota

I. Reducing Nitrate losses with a scavenger crop.

Objective 2. To screen potential nitrate-N scavenger crops for corn/soybean systems.

Experiment II. Cereal rye cover crop variety evaluation

- Tables 1-3
- Figure 1

Table 1. Rye cultivar trial management practices.

Location:	Morris	Lamberton	Waseca	Roseau	St. Paul
Rye Planted:	10-Oct-00	05-Oct-00	26-Sep-00	15-Sep-00	18-Sep-00
Rye Row Width:	7.5"	7.5"	8"	6"	8"
Previous Crop:	corn	corn	corn	canola	corn
Residue Management:	no-till	no-till	no-till	chisel	silage/NT
Spring Snow Melt:	06-Apr-01	06-Apr-01	04-Apr-01	26-Mar-01	01-Apr-01
Rye Kill Date:	18-May-01	16-May-01	01-Jun-01	11-May-01	16-May-01
Method to Kill Rye:	Roundup	Roundup	Roundup	Roundup	Flail mower
Soybean Planted:	30-May	29-May	1-Jun	12-Jun	4-Jun
Soybean Row Width:	7"	7.5"	10"	7"	10"

Table 2. Rye biomass, N concentration and N uptake just after snow melt.

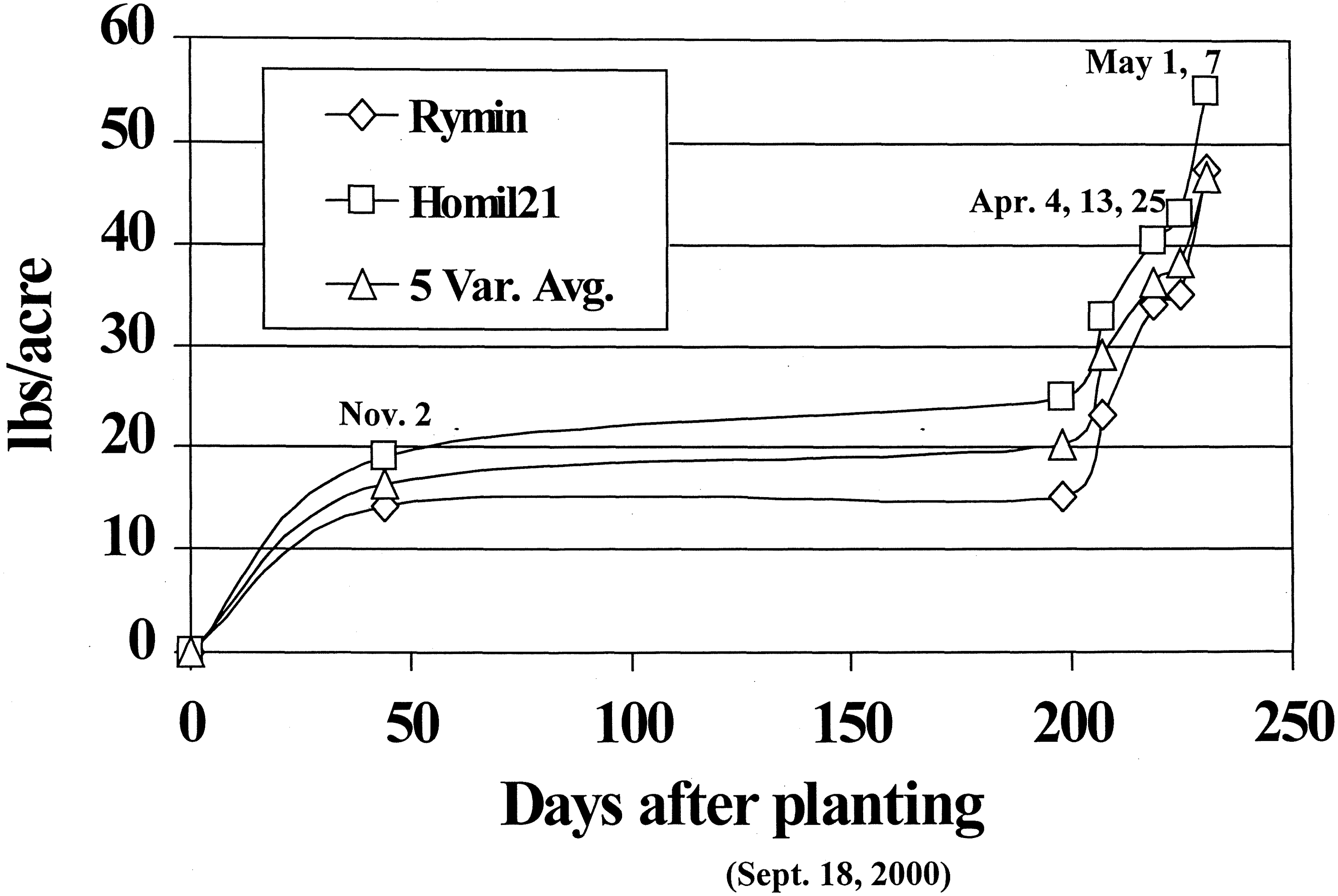
	Lamberton	Roseau	St. Paul	Mean	% of
Rye Planted:	Oct. 5	Sept. 15	Sept. 18		
Sample Date:	Apr. 10	Mar. 28	Apr. 4		**Homil21**
ABOVEGROUND BIOMASS:					
Cultivar		**lbs/acre**			
Rymin	58	327	390	**259**	*63*
Dakota	43	189	496	**242**	*59*
Homil21	134	441	657	**411**	*100*
Homil22	80	297	505	**294**	*72*
Dacold	160	372	558	**363**	*88*
Statistics					
Mean	95	325	521	**314**	
CV (%)	22.2	21.2	26.5		
Pr>f	0.0001	0.0031	0.1627		
ABOVEGROUND NITROGEN UPTAKE:					
Cultivar		**lbs N /acre**			
Rymin		15.1	15.1	**15.1**	*67*
Dakota		8.6	19.9	**14.2**	*64*
Homil21		19.7	25.1	**22.4**	*100*
Homil22		13.0	19.9	**16.5**	*73*
Dacold		16.4	21.9	**19.1**	*85*
Statistics					
Mean		14.5	20.4	**17.5**	
CV (%)		20.0	23.4		
Pr>f		0.0021	0.1120		
NITROGEN PERCENTAGE IN TISSUE:					
Cultivar		% N			
Rymin		4.64	3.85	**4.24**	*102*
Dakota		4.53	3.98	**4.25**	*103*
Homil21		4.48	3.80	**4.14**	*100*
Homil22		4.37	3.91	**4.14**	*100*
Dacold		4.38	3.90	**4.14**	*100*
Statistics					
Mean		4.48	3.89	**4.18**	
CV (%)		3.30	6.70		
Pr>f		0.1198	0.9058		

Table 3. Rye biomass, N concentration and N uptake in early May.

	Morris	Lamberton	Waseca	Roseau	St. Paul	Mean	
Rye Planted:	Oct. 10	Oct. 5	Sept. 26	Sept. 15	Sept. 18		% of
Sample Date:	May 6	May 6	May 6	Apr. 30	May 7		Homil21
ABOVEGROUND BIOMASS:							
Cultivar			lbs/acre				
Rymin	71	91	212	878	2069	**664** c	*75*
Dakota	43	81	179	529	1965	**559** d	*63*
Homil21	106	209	420	1064	2634	**887** a	*100*
Homil22	90	194	250	835	1718	**617** cd	*70*
Dacold	87	194	330	1082	2176	**774** b	*87*
Statistics							
Mean	79	154	278	878	2112	**700**	
CV (%)	29.2	21.4	37.8	22.6	11.8	21.3	
Pr>f	0.0065	0.0002	0.0434	0.0229	0.0021	0.0001 (Cultivar)	
						0.0001 (Location)	
						0.0001 (Cult.*Loc.)	
ABOVEGROUND NITROGEN UPTAKE:							
Cultivar			lbs N /acre				
Rymin	2.3	3.5	8.7	20.5	47.4	**16.5** b	*78*
Dakota	1.5	3.6	7.8	15.2	43.1	**14.2** b	*67*
Homil21	3.2	7.1	15.8	24.6	55.2	**21.2** a	*100*
Homil22	2.9	7.2	10.2	20.2	39.6	**16.0** b	*76*
Dacold	2.7	7.3	13.0	25.7	48.7	**19.5** a	*92*
Statistics							
Mean	2.5	5.7	11.1	21.2	46.8	**17.5**	
CV (%)	31.7	22.0	33.3	20.6	15.1	23.8	
Pr>f	0.0372	0.0008	0.0538	0.0592	0.0712	0.0001 (Cultivar)	
						0.0001 (Location)	
						0.0664 (Cult.*Loc.)	
NITROGEN PERCENTAGE IN TISSUE:							
Cultivar			% N				
Rymin	3.26	3.78	4.15	2.38	2.24	**3.16** b	*108*
Dakota	3.56	4.41	4.37	2.99	2.25	**3.51** a	*120*
Homil21	3.02	3.37	3.82	2.32	2.10	**2.92** c	*100*
Homil22	3.23	3.63	4.11	2.42	2.32	**3.14** b	*107*
Dacold	3.04	3.76	4.04	2.38	2.26	**3.10** bc	*106*
Statistics							
Mean	3.22	3.79	4.10	2.50	2.23	**3.17**	
CV (%)	8.2	5.8	6.4	9.3	9.4	7.6	
Pr>f	0.0334	0.0004	0.1172	0.0128	0.6801	0.0001 (Cultivar)	
						0.0001 (Location)	
						0.0001 (Cult.*Loc.)	

Rye Aboveground Nitrogen

St. Paul



Result 2. Cover crops for southern Minnesota

II. Evaluating legumes intercropped in small grains

- **Tables 1-13**

Table 1: Seeding rates for cultivars

Cultivar	Seeding rate (kg/ha)
Wheat '2375'	168
Oat 'Dane'	108
Alfalfa 'Nitro +'	17
Red clover 'Mammoth'	13
Bur medic 'Santiago'	17*
Yellow sweet clover	17
Berseem clover 'Bigbee'	17

*Seeding rate was increased to 28 kg/ha in 2000 to compensate for low germination.

Table 2:Experimental designs of 1999 and 2000 SWROC experiments

ANOVA: 1999		ANOVA:2000	
Source of variation	df	Source of variation	df
Tillage [T]	1	Tillage [T]	1
Block	3	Block	3
Error a	3	Error a	3
Small grain [SG]	1	Small grain [SG]	1
Legume species [L]	4	Legume species [L]*	5
SG x L	4	SG x L	5
T x SG	1	T x SG	1
T x L	4	T x L	5
T x SG x L	4	T x SG x L	5
Error b	54	Error b	66
Underseed [U]	1		
T x U	1		
SG x U	1		
L x U	4		
SG x L x U	4		
T x SG x U	1		
T x L x U	4		
T x SG x L x U	4		
Error c	60		

* Legume in the 2000 includes a no legume treatment.

Table 3: On-farm experiments in 2000

Farmer	Location	Planting date	Small grain	Legume treatments
Carmen Fernholz	Madison, Lac Qui Parle County	4/2/00	Oat (no-till planted)	1)Nitro alfalfa 2)Santiago medic 3)Berseem clover
Larry Olsen	Montevideo, Chippewa County	3/30/00	Barley	1)Nitro alfalfa 2)Red clover 3)Yellow sweetclover 4) No underseed
Eldon Mitzner	Tracy, Lyon County	4/4/00	Barley	1)Redclover/yellow sweetclover mix 2)Santiago medic 3) Berseem clover
Don DeWeerd	Pipestone, Pipestone County	4/24-25/00	Barley	1) Nitro alfalfa 2) Mammoth red clover 3)Yellow sweetclover 4) No underseed

Table 4: Legume aboveground dryweight accumulation (Mg ha^{-1}) at small grain harvest and at end of growing season: 1999

Legume	Aboveground dryweight at small grain harvest*	Fall aboveground dryweight
Red clover	0.19a	0.78a
Alfalfa	0.12ab	0.64a
Yellow sweetclover	0.06bc	0.42b
Berseem clover	0 .01c	0.03c
Santiago medic	0.01c	0.02c

*Means followed by a common letter are not significantly different ($p \leq 0.05$) as determined by Tukey's Studentized Range Test.

Table 7: Legume aboveground biomass (Mg ha^{-1}) at fall sampling in the legume underseed on-farm experiments

Small grain/legume underseed	Deweerd	Olsen	Mitzner	Fernholz
Barley/Nitro+ alfalfa	0.35a*	0.45ab	--	--
Barley /Mammoth red clover	0.56a	0.19b	--	--
Barley/Yellow sweetclover	0.54a	0.82a	--	--
Barley/Annual medic	--**	--	0.00b	--
Barley/Berseem clover	--	--	0.03b	--
Barley/Mammoth red clover and yellow sweetclover mix	--	--	0.96a	--
Barley/No underseed	--	--	--	--
Oat/Nitro+ alfalfa	--	--	--	0.55a
Oat/Annual medic	--	--	--	0.00b
Oat/Berseem clover	--	--	--	0.07b
Oat/no underseed	--	--	--	--

*Within a column, means followed by the same letter do not differ significantly ($p<0.05$).
**Treatment not included at site.

Table 8 Weed drymatter accumulation (Mg ha^{-1}) at small grain harvest in on-farm experiments

	DeWeerd		Olsen		Mitzner		Fernholz	
Small grain/legume	Grass	Broadleaf	Grass	Broadleaf	Grass	Broadleaf	Grass	Broadleaf
Barley/alfalfa	2.38a*	0.35a	0.27a	0.75a	--**	--	--	--
Barley/mammoth red clover	2.13a	0.41a	0.28a	0.43a	--	--	--	--
Barley/yellow sweetclover	1.53a	0.40a	0.08a	0.33a	--	--	--	--
Barley/no underseed	2.04a	0.22a	0.23a	0.45a	--	--	--	--
Barley/Annual medic	--	--	--	--	0.60a	0.01a		
Barley/berseem clover	--	--	--	--	0.74a	0.01a		
Barley/ mammoth red clover + yellow sweetclover	--	--	--	--	0.27b	0.01a	--	--
Oat/alfalfa	--	--	--	--	--	--	1.12a	0.37a
Oat/annual medic	--	--	--	--	--	--	1.00a	0.33a
Oat/berseem clover	--	--	--	--	--	--	0.98a	0.19a
Oat/no underseed	--	--	--	--	--	--	0.98a	0.45a

*Wihtin column, means followed by the same letter do not differ significantly ($p<0.05$).
**Treatment not included at the site.

Table 9: Aboveground drymatter accumulation (Mg ha^{-1}) of broadleaf weeds at small grain harvest: 1999

Legume	No-till planting	Disk planting
alfalfa	0.16	0.22
red clover	0.24	0.18
Santiago medic	0.18	0.29
Yellow sweetclover	0.17	0.21
Berseem clover	0.19	0.23
	ANOVA[a]	
Source		
Tillage	ns	
Legume	ns	
Tillage x legume	*	

[a] * Significant at 0.05; ns = not significant

Table 10 Weed drymatter accumulation (Mg ha^{-1}) at small grain harvest in the SWROC experiment: 2000

Crop	Grass	Broadleaf
Wheat	0.92	0.33
Oat	1.53	0.62
	ANOVA	
Source		
Crop	****	**

[a]Significance levels: ****, p<0.0001; ** ,p<0.01

Table 11: Wheat and oat grain and straw yields (Mg ha^{-1}) with and without legume underseeds:1999

	Grain yield		Straw yield	
Small grain	With underseed	Without underseed	With underseed	Without underseed
Wheat	1.24	1.26	2.20	2.20
Oat	1.80	2.07	1.41	1.57
	ANOVA[a]			
Source				
Small grain	****		****	
Underseed (+/-)	**		ns	
Small grain x underseed	**		ns	

[a] *, **, **** Significant at 0.05, 0.01, and 0.0001; ns= not significant

Table 12: Small grain yield (Mg ha^{-1}) in the legume underseed on-farm experiments

Small grain/legume underseed	Deweerd	Olsen	Mitzner	Fernholz
Barley/Nitro+ alfalfa	1.86a*	2.55a	--	--
Barley /Mammoth red clover	1.94a	2.73a	--	--
Barley/Yellow sweetclover	1.84a	2.71a	--	--
Barley/Annual medic	--**	--	1.77a	--
Barley/Berseem clover	--	--	1.72a	--
Barley/Mammoth red clover and yellow sweetclover mix	--	--	1.70a	--
Barley/No underseed	1.96a	2.85a	--	--
Oat/Nitro+ alfalfa	--	--	--	2.07a
Oat/Annual medic	--	--	--	1.82a
Oat/Berseem clover	--	--	--	2.23a
Oat/no underseed	--	--	--	2.24a

*Within a column, means followed by the same letter do not differ significantly ($p<0.05$).
**Treatment not included at this site.

Table 13
Small grain yield (Mg ha^{-1}) in SWROC experiment: 2000

Preplant tillage	Wheat	Oat
No-till	1.88	0.52
Disk	1.97	0.81
	ANOVA[a]	
Source		
Small grain	****	
Small grain *till	*	

[a]Significance levels: ****, $p< 0.0001$; * $p<0.05$

Result 2. Cover crops for southern Minnesota

III. Kura clover as a perennial living mulch

- Tables 1-4
- Kura clover living mulch information fact sheet

III. Kura clover as a perennial living mulch.

Table 1. Corn population, grain yield (grn yld), whole-plant nitrogen concentration (N) and fall legume dry matter yield for the corn - Kura clover interseed trial at Rosemount, MN in 2000. | Spring Kura population and forage dry matter yield in 2001.

Treatment: Tillage [1]	Treatment: Legume Entry/ Nitrogen Application [2]	Corn [3] population	Corn [3] grn yld @ 15.5%	Corn [3] N	Fall legume dry matter yield	Kura [4] tillers	Kura [4] dm yield
		plant/ acre	bu/ acre	%	lb/ acre	tiller/ ft^2	ton/ acre
Fall Chisel Plow - Spring Disk	Endura KC 0-N	22051	131	0.97	1301	6	0.9
	Endura KC 150-N	24256	127	1.30	1351	6	0.8
	Rhizo KC 0-N	25173	148	0.96	1176	3	0.4
	Rhizo KC 150-N	25557	144	1.32	1401	4	1.1
	Norcen BFT 0-N	23604	140	0.94	--	--	--
	Norcen BFT 150-N	27188	161	1.11	--	--	--
	mean	**24638**	**142**	**1.10**	**1307**	**5**	**0.8**
	LSD(0.05)	**ns**	**21**	**0.17**	**ns**	**2**	**ns**
Spring Disk	Endura KC 0-N	15789	63	0.80	2252	9	1.5
	Endura KC 150-N	17944	45	1.68	2902	8	1.2
	Rhizo KC 0-N	15293	62	0.88	2164	6	1.6
	Rhizo KC 150-N	17944	57	1.68	2252	7	1.1
	Norcen BFT 0-N	25261	130	0.72	--	--	--
	Norcen BFT 150-N	23630	133	1.06	--	--	--
	mean	**19310**	**82**	**1.14**	**2393**	**8**	**1.4**
	LSD(0.05)	**7119**	**29**	**0.29**	**ns**	**ns**	**0.4**
	Tillage treatment LSD(0.05)	**1109**	**16**	**ns**	**349**	**1**	**ns**
	Interaction LSD(0.05)	**5331**	**24**	**0.22**	**ns**	**ns**	**0.4**

(1) - *Fall Chisel Plow - Spring Disk* tillage treatment block plowed 10 October 1999 and disked twice, 16 April 2000 and 3 May 2000.
- *Spring Disk* tillage treatment disked twice, 16 April 2000 and 3 May 2000.

(2) - Ammonium nitrate fertilizer applied to corn fertilty plots at the 4-leaf stage on 5 June 2000.

(3) - Corn plant counts, harvest for grain yield and whole plant sampling and legume harvest for forage yield done on 5 October 2000.

(4) - Spring Kura clover tiller counts done on 19 April 2001; Spring forage harvest done on 5 June 2001.

III. Kura clover as a perennial living mulch.

Table 2. Corn population, grain yield (grn yld), whole-plant nitrogen concentration (N) and fall legume dry matter yield for the corn - Kura clover interseed trial at Becker, MN in 2000.

Spring Kura population and forage dry matter yield in 2001.

Treatment: Tillage (1)	Treatment: Legume Entry/ Nitrogen Application (2)	Corn (3) population	Corn (3) grn yld @ 15.5%	Corn (3) N	Fall legume dry matter yield	Kura (4) tillers	Kura (4) dm yield
		plant/ acre	bu/ acre	%	lb/ acre	tiller/ ft^2	ton/ acre
Fall and Spring Disk	Endura KC 0-N	30768	146	0.81	437	6	0.5
	Endura KC 150-N	28420	144	0.90	760	6	0.7
	Rhizo KC 0-N	31340	142	0.90	198	6	0.5
	Rhizo KC 150-N	30457	159	0.86	154	6	0.4
	mean	**30246**	**148**	**0.87**	**387**	**6**	**0.5**
	LSD(0.05)	**ns**	**ns**	**ns**	**331**	**ns**	**ns**
Spring Disk	Endura KC 0-N	23391	116	1.07	2109	8	0.9
	Endura KC 150-N	25272	127	0.93	1792	9	0.9
	Rhizo KC 0-N	13616	70	0.96	2552	11	1.2
	Rhizo KC 150-N	25327	131	0.99	1349	9	0.8
	mean	**21902**	**111**	**0.99**	**1951**	**9**	**1.0**
	LSD(0.05)	**ns**	**48**	**ns**	**ns**	**ns**	**ns**
	Tillage treatment LSD(0.05)	**ns**	**23**	**ns**	**1360**	**2**	**0.1**
	Interaction LSD(0.05)	**ns**	**ns**	**ns**	**669**	**ns**	**0.2**

(1) - *Fall Disk - Spring Disk* tillage treatment block disked twice on 15 October 1999 and disked twice at planting on 28 April 2000.
- *Spring Disk* tillage treatment block disked twice on 28 April 2000.

(2) - Ammonium nitrate fertilizer applied to corn fertility plots in split application. 100 lb N applied on 26 May 2000 and 50 lb N on 11 July 2000.

(3) - Corn plant counts, harvest for grain yield and whole plant sampling and legume harvest for forage yield done on 9 October 2000.

(4) - Spring Kura clover tiller counts done on 20 April 2001; Spring forage harvest done on 30 May 2001.

Table 3.

Becker soil test results sampled on 6 June 2001.

Treatment	Depth	Rep	pH	Bray P	K	NO_3-N	Bray P	K	NO_3-N
				lb/ acre			ppm		
Check Plots	1 - 12"	1	6.6	54	366	22.2	27	183	11.1
(BFT prior to 2001)		2	6.3	54	312	16.6	27	156	8.3
		3	6.7	40	366	5.8	20	183	2.9
		mean	**6.5**	**49**	**348**	**14.9**	**25**	**174**	**7.4**
	13 - 24"	1	6.3	30	170	13.4	15	85	6.7
		2	5.8	34	136	14	17	68	7
		3	6.7	24	148	6.2	12	74	3.1
		mean	**6.3**	**29**	**151**	**11.2**	**15**	**76**	**5.6**
Endura Plots	1 - 12"	1	6.6	50	330	13.8	25	165	6.9
		2	6.5	54	310	24.2	27	155	12.1
		3	6.7	58	330	19.2	29	165	9.6
		mean	**6.6**	**54**	**323**	**19.1**	**27**	**162**	**9.5**
	13 - 24"	1	6.6	34	152	9.6	17	76	4.8
		2	6.5	38	126	11.8	19	63	5.9
		3	6.6	26	100	14.6	13	50	7.3
		mean	**6.6**	**33**	**126**	**12.0**	**16**	**63**	**6.0**
Rhizo Plots	1 - 12"	1	6.6	56	364	29.2	28	182	14.6
		2	6.6	48	360	23.2	24	180	11.6
		3	6.5	52	434	15.2	26	217	7.6
		mean	**6.6**	**52**	**386**	**22.5**	**26**	**193**	**11.3**
	13 - 24"	1	6.2	42	162	12.6	21	81	6.3
		2	6.4	40	148	12.2	20	74	6.1
		3	6.2	28	106	5.6	14	53	2.8
		mean	**6.3**	**37**	**139**	**10.1**	**18**	**69**	**5.1**

Table 4
Rosemount soil test results sampled on June 2001.

Treatment	Depth	Rep	pH	Bray P	K	NO_3-N	Bray P	K	NO_3-N
				lb/ acre			ppm		
Check Plots	1 - 12"	1	6.4	20	248	42.2	10	124	21.1
(BFT prior to 2001)		2	6.4	16	186	36.2	8	93	18.1
		3	6.7	24	236	18.6	12	118	9.3
		mean	**6.5**	**20**	**223**	**32.3**	**10**	**112**	**16.2**
	13 - 24"	1	6.4	16	204	18.2	8	102	9.1
		2	6.5	18	186	14.6	9	93	7.3
		3	7	18	176	5.8	9	88	2.9
		mean	**6.6**	**17**	**189**	**12.9**	**9**	**94**	**6.4**
Endura Plots	1 - 12"	1	6.7	20	198	31.8	10	99	15.9
		2	6.6	20	214	40.2	10	107	20.1
		3	6.5	20	222	28.6	10	111	14.3
		mean	**6.6**	**20**	**211**	**33.5**	**10**	**106**	**16.8**
	13 - 24"	1	6.9	20	164	5.4	10	82	2.7
		2	6.7	14	188	21.2	7	94	10.6
		3	6.4	18	158	9.8	9	79	4.9
		mean	**6.7**	**17**	**170**	**12.1**	**9**	**85**	**6.1**
Rhizo Plots	1 - 12"	1	6.4	22	260	40.4	11	130	20.2
		2	6.6	12	182	33.8	6	91	16.9
		3	6.4	16	274	39.6	8	137	19.8
		mean	**6.5**	**17**	**239**	**37.9**	**8**	**119**	**19.0**
	13 - 24"	1	6.6	24	190	25.2	12	95	12.6
		2	6.5	22	152	10.2	11	76	5.1
		3	6.4	16	156	24.4	8	78	12.2
		mean	**6.5**	**21**	**166**	**19.9**	**10**	**83**	**10.0**

A Kura Clover Living Mulch System for Corn Production

Introduction

The advantages and challenges of living mulch systems.

Living mulch systems involve planting a grain crop such as corn into a living but suppressed legume sod that can recover following harvest of the grain crop. Legume living mulches can provide ground cover for erosion control and suppress weeds during crop growth. Fall and winter ground cover provided by regenerated legumes is especially valuable for reduction of erosion normally associated with row crops and can provide valuable livestock feed.

The challenge with a living mulch system is to suppress living plants so as to avoid competition during germination and early season growth of the corn crop while allowing for sufficient sod recovery to provide soil surface cover beneath the crop canopy; however; this balance is difficult to achieve. Therefore, living mulch systems require careful season-long monitoring. Most successful living mulch systems depend on specialized no-till and spraying equipment and strategic use of herbicides and or tillage because perennial legumes often have greater resistance to herbicides than annuals. Schultz et al. (1987) recommended that an effective perennial living mulch system should involve use of residual soil-active herbicides, aggressive control of annual and perennial weeds, establishing 30-cm wide legume kill bands, and application of a starter N fertilizer since suppressed legumes appear to compete with corn for N. In a successful kura clover living mulch system used in Wisconsin, glyphosate is applied in 61-cm strips centered on corn with 15-cm of untreated kura clover between rows (Zemenchik et al., 2000). Annual grass and broadleaf control were achieved through application of herbicides.

Kura clover

Kura clover (*Trifolium ambiguum* Bieb.) is a relatively low growing, spreading perennial legume with excellent potential to be productive and persistent in the Northern USA. It is also called Caucasian, Pelletts, or honey clover. Its primary use in agriculture is as a grazing crop because of its prostrate growth habit and forage that is very leafy and high in moisture content, but the first growth in the spring can also readily be harvested for hay. Because of its excellent persistence and spreading growth habit, kura has great potential for soil cover and erosion control in agricultural and nonagricultural areas.

Objective

A Kura Clover living mulch system offers the potential to provide grain production while minimizing environmental degradation normally associated with conventional tillage practices. For widespread use we felt that a simplified system using readily available farm technology would provide for the greatest use of the living mulch system.

Methodology

We developed and evaluated a kura clover living mulch system in field research at Rosemount and Becker, MN. The soil at Rosemount is a Waukegan silt loam and at Becker a Hubbard loamy sand. The Rosemount soil is derived from loess parent material and has an organic matter content of about 3%; whereas, the Becker soil is derived from glacial outwash and has an organic matter content of about 1%. Consequently, the course textured Becker soil is naturally lower in soil N and general fertility. It also requires irrigation to achieve crop yields.
Each location had 2-year-old stands of two Kura clover varieties, Rhizo and Endura.

At each location, we imposed the following treatments:

- Two kura clover varieties: Rhizo and Endura.
- Two suppression levels achieved by two levels of tillage: Fall and spring disking vs. spring disking alone.
- Two levels of N fertilizer: 0 and 150 lb/acre.

Tillage treatments achieved two levels of Kura clover suppression and provided for a clean seed bed for seeding of Round-up ready corn with a conventional corn planter in May. Nitrogen fertilizer was applied at planting. Kura clover regrowth following spring tillage and corn planting was suppressed via application of Roundup at a rate of 1 quart per acre. To control annual broadleaf weeds and grasses we also applied Lasso at planting

Summary

- Yield data is shown in Tables I and 2.
- With a high level of suppression of kura clover through multiple tillage operations or a combination of tillage plus Round-up (Glyphosate) herbicide application grain production levels could be obtained that were similar to conventional tillage production systems and a living mulch provided.
- When used as a living mulch, suppressed Kura clover regrew following corn harvest and provided forage for harvest in the following year.

Table 1. Corn grain yield (at 15.5% moisture) and fall and spring kura yield for kura clover living mulch study at Becker and Rosemount, MN.

Tillage [(1)]	Legume Entry/Nitrogen Application [(2)]	Becker Corn Yield	Becker *Kura Yield* Fall	Becker *Kura Yield* Spring	Rosemount Corn Yield	Rosemount Kura Yield Fall	Rosemount Kura Yield Spring
		bu/acre	lb/acre	ton/acre		lb/acre	ton/acre
Fall Disk/Chisel Plow[(3)] and Spring Disk	Endura KC 0-N	146	437	0.5	131	1301	0.9
	Endura KC 150-N	144	760	0.7	127	1351	0.8
	mean	**148**	**387**	**0.5**	**142**	**1307**	**0.8**
	LSD (0.05)	**ns**	**331**	**ns**	**21**	**ns**	**ns**
Spring Disk	Endura KC 0-N	116	2109	0.9	63	2252	1.5
	Endura KC 150-N	127	1792	0.9	45	2902	1.2
	mean	**111**	**1951**	**1.0**	**82**	**2393**	**1.4**
	LSD (0.05)	**48**	**ns**	**ns**	**29**	**ns**	**0.4**

(1) Becker: Fall Disk – Spring Disk tillage treatment block disked twice on 15 October 1999 and disked twice at planting on 28 April 2000. Rosemount: Fall Chisel Plow – Spring Disk tillage treatment block plowed 10 October 1999 and disked twice, 16 April 2000 and 3 May 2000.

(2) Becker: Ammonium nitrate fertilizer applied to corn fertility plots in split application. 100 lb N applied on 26 May 2000 and 50 lb N on 11 July 2000. Rosemount: Ammonium nitrate fertilizer applied to corn fertility plots at the 4-leaf stage on 5 June 2000.

(3) Chisel Plow used at Rosemount only.

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Result 3. Agroforestry

- **Table 1-2**
- **Hazelnut Information leaflet**

Apendix Hazelnut Growth Summary for 2000

S = statistically significant between treatments,
NS = not statistically significant between treatments
two tailed t-test, 95% confidence

Statistics	Comparisons between practices	Date Planted	Surviving plants	Percent mortality	Average height (in.)	Average # of Branches	Average # of Sprouts	Average herbivory**
Morris Trials								
	Wool mulch vs Cultivation	6-Jun-00	NS	NS	NS	NS	NS	NS
	Landscape Fabric vs Cultivation	6-Jun-00	NS	NS	NS	NS	NS	NS
	Wool mulch vs Landscape Fabric	6-Jun-00	S	NS	NS	NS	NS	NS
Staples Tials								
	Wood Mulch vs Cultivation	10-Jul-00	NS	NS	NS	NS	NS	NS
Lamberton Trials	Landscape Fabric vs Wood Multch	6-Jul-00	S	NS	NS	NS	NS	NS

Field Data	Management Practice	Date Planted	Hazels planted	Surviving plants	Percent mortality	Average height (in.)	Average # of Branches	Average # of Sprouts	Average herbivory**
Staples	irrigated								
	Cultivation	10-Jul-00	144	139	3.47%	7.59	0.65	0.03	1.11
	Wood Mulch	10-Jul-00	144	141	2.08%	6.65	0.65	0.04	1.30
	Cultivation, Windbreak	3-Jul-00	102	88	13.73%	7.44	0.69	0.05	1.12
Morris	irrigated								
	Cultivation	6-Jul-00	76	63	17.11%	7.19	0.37	0.06	1.85
	Wool mulch	6-Jul-00	87	78	10.34%	5.68	0.59	0.12	1.41
	Landscape Fabric	6-Jul-00	89	69	22.47%	6.75	0.96	0.12	1.39
Jackson	not irrigated								
(Lamberton)	Wood Mulch	6-Jul-00	96	92	4.17%	7.78	1.45	0.21	1.20
	Landscape Fabric (with wood mulch)	6-Jul-00	96	80	16.67%	7.53	1.36	0.14	1.36
Farm Trials									
	Gibson, Chippewa County								
	Cultivation, not irrigated	6-Jun-00	194	171	11.86%	5.95	0.66	0.05	1.01
	North Central Group	July	82	73	10.98%	7.10	0.59	0.08	1.40
	West Central Group	July	84	55	34.52%	7.55	NA	NA	NA
	South West Group	July	76	40	47.37%	7.78	0.88	0.00	1.05
	Total for Farm Trials		*416*	*319*	*23.32%*	*7.23*	*NA*	*NA*	*NA*
Totals			**1270**	**1089**	**14.25%**	**7.34**	**0.73**	**0.07**	**1.16**

*Per plant

**Ranked from 1 to 5, 1= none, 2= up to 1/3, 3=1/3 to 2/3, 4= more than 2/3, 5= defoliated

Field Data Continued

			Average Growth (in.)	Growth w/o damage (in.)	Best Growth (in)	# of new Branches	# of new Sprouts
Staples		irrigated					
	Cultivation		0.08	0.82	3	0.32	0.13
	Wood Mulch		0.04	0.85	5	0.25	0.02
	Cultivation, Windbreak		0.50	3.58	8	0.58	0.03
Morris		irrigated					
	Cultivation		1.21	5.26	14	0.90	-0.03
	Wool mulch		-0.83	2.65	14	0.44	0.02
	Landscape Fabric		1.03	1.64	13	0.84	0.12
Jackson		not irrigated					
(Lamberton)	Wood Mulch		-0.83	2.6	7	0.28	0.00
	Landscape Fabric (with wood mulch)		0.67	5.625	19	0.25	0.10
Farm Trials							
	Gibson, Chippewa County		-0.72	0.10	1	0.66	0.04
	North Central Group						
	West Central Group						
	South West Group						
	Total for Farm Trials		*NA*	*NA*	*NA*	*NA*	*NA*
Totals			**0.00**	**2.06**	**19**	**0.44**	**0.04**

Statistics For Hazelnut Varieties

S = statistically significant between treatments,

NS = not statistically significant between treatments

two tailed t-test, 95% confidence

	Comparisons between practices	Date Planted	Percent mortality	Average height (in.)	Average # of Branches	Average # of Sprouts	Average herbivory
Staples Tials							
	P1 vs P2	10-Jun-00	NS	S, P2 > P1	NS	NS	NS
	P2 vs P3	10-Jun-00	NS	S, P2 > P3	S, P3 < P2	NS	NS
	P1 vs P3	10-Jun-00	NS	NS	S, P3 < P1	NS	NS
Lamberton Trials	Native vs Hybrid Hazelnut	6-Jul-00	NS	S, Native>Hybrid	NS	NS	NS

Hazelnut field note summary means and least significant difference (LSD) for plant hieght and survival (stand) following planting on 11 July 2000 at Rosemount, MN.

Fertility treatment	Hazelnut entries	14 June 2001 field notes height	stand
		cm	%
Check, 0 # K applied	M2	16	90
	S1 - 282	22	100
	x2.2 y2.0	21	97
	mean	**20**	**96**
	lsd 0.05	**ns**	**7**
100 # K applied	M2	18	90
	S1 - 282	22	100
	x2.2 y2.0	20	100
	mean	**20**	**97**
	lsd 0.05	**3**	**ns**
200 # K applied	M2	17	97
	S1 - 282	21	93
	x2.2 y2.0	20	100
	mean	**19**	**97**
	lsd 0.05	**ns**	**ns**
Fertility treatment	lsd 0.05	**ns**	**ns**
Fertility x entry interaction	lsd 0.05	**ns**	**ns**

Draft Hazelnut Information Leaflet

July 1, 2001

Overview of Hazelnuts

In the Upper Midwest there is a growing interest in utilizing woody plants as a means to overcome some of agriculture's challenges in regards to market and the environment. At the same time, producers are actively searching for profitable crops and production systems to diversify their farming operations (Joannides, 1997). Under-utilized and potentially profitable supplements to traditional crops and cropping systems are woody plants that can produce food, fiber, and biomass. The woody plants can be incorporated into agricultural systems as agroforestry plantings such as field windbreaks, living snowfences, or riparian buffers.

The concept of incorporating woody plants into agricultural systems is known as agroforestry. Agroforestry is an intensive land management system that strives to optimize the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or animals (Garrett et al., 1996).

Hybrid hazelnut varieties have been under development at Badgersett Research Farm in SE Minnesota for the past twenty years. Now that high-performance genetic material has been developed, these hazels are attracting great interest from landowners. The hazelnuts developed have been bred to be hardy to Minnesota's climate, resistant to Eastern Filbert Blight, and able to produce nuts on a commercial scale (Rutter, 1988). The hazelnut industry is well established in other parts of the world. Hazelnuts are marketed in unshelled and shelled forms, roasted or salted, and are currently used primarily in the confectionery industries, and for the preparation of several food products. In the United States, 99% of hazels are grown in the Pacific Northwest; yet this area meets only 10% of the domestic hazelnut market demand. Currently there has been no commercial production in the Midwest because until recently the only hazels well adapted to this area were wild types which produce only small, inconsistent crops.

Hazelnuts have potential for incorporation into agricultural systems in Minnesota to provide environmental and economic benefits. This is true particularly in marginal and erosion prone area where a perennial crop may overcome some of the barriers faced by traditional row cropping.

Establishment, Cultivation and Fertilization:

Recommended spacing for hybrid hazelnuts is 3-5' apart for windbreaks, and 4-10' apart for nuts. They alternate rows 10' and 15' apart. The 10' rows eventually get so tight that one can not get a tractor through for harvest or fertilizer; the 15' rows stay open.

To prepare a row, plant as if planting any other tree, plow the sub-soil, disk it smooth and then plants the tublings a round of herbicide can be used. Hand or machine plant the hazelnut plants into firm cultivated ground. <u>Water if needed in the first year only</u> (rain or water once every two weeks).

To deal with weed competition landscape fabric, cultivation, and a wood-chip mulch have been tried. Trials that used a landscape fabric ground mat showed high mortality due to pests and heat stress. Others found that the warm black mat attracted insects and mice in the fall. Badgersett Research Corporation has used a ground mat but did not like it, keeping it down in the wind proved difficult and it drew attention to the plants when the rabbits were hungry.

Several farmers found that staking down the mat, cutting larger holes (10 in) and placing wood chips around the plant on top of the mat was effective initially. In Jackson, MN this technique was used and overcame the problems caused by the landscape fabric.

If using cultivation, cultivate shallowly for 2 years. Black soil can heat the plants excessively. Alternatively mowing can control weeds; hazelnuts are excellent root competitors. After several years the hazelnuts will out-compete the surrounding weeds.

Wood chip mulches were used on several plots with much success. One should mulch close to the plant (but not touching the stem) if feasible.

Badgersett Research Corporation suggests that moderately applying fertilizer in the first year will greatly speed growth. Specific recommendations have not been developed yet. Though, for plants bearing nuts they suggest following local guidelines for corn, but add more potash (as much as double). Hazelnuts need nitrogen in early-mid September to form good female flower buds. This has no effect on the cold-hardiness of Hybrid Hazelnuts. In addition, organic fertilizers should be just as or more effective than chemical fertilizers.

Growth:

This information depends greatly on management and climate. One would expect plants growing in colder regions or with little weed control to grow slower. There are Hybrid Hazelnuts as far North as the Canadian border. Once established, hazelnuts can survive both drought and flood.

Hybrid Hazelnuts start slowly. Growing little above the ground for the first three years. During this time the plants are putting out an extensive root system. By the fourth year the hazelnuts start to put on more top growth and may produce some nuts. By the fifth year a row 150 yards long may yield about 20 lbs. of nuts. When a bush reaches eight years it may produce between 1-2 lbs. of nuts and stands about 7 feet tall. Preliminary research on hybrid hazels indicates that they can produce from 800 to 2000 pounds of nuts per acre per year (Pellett et al. 1998).

After several years of production a bush can be coppiced (cut back). This normally invigorates growth and nut production. In order to get a harvest the next year it is suggested that the grower leave 20 % of the sprouts and cut the rest at ground level (nuts develop on last years growth). Sometimes a bush that gave poor harvests before the coppice will improve afterwards.

Pests:

In twenty years of research the Badgersett Research Corporation has had no economically significant pest problem affect their plantings. They did have a significant loss when they attempted to plant the hazelnuts as nuts into the field. Birds and rodents devastated the planted seed. This led to their seedling operation going indoors.

Hazels are not favorite browse, but deer and rabbits will sometimes hit fast growing young plants. Badgersett Research Corporation sprays egg (12 dozen eggs blended into 5 gallons of water) to repel them. This is not a problem for mature bushes as they recover very quickly. Deer do eat male flowers in winter and spring; they may eat ALL male catkins below 4' high, if pressure is heavy. Wire structures can be constructed around the seedlings if desired.

Winter-kill by rodents can be a problem. This was especially noted with landscape fabric ground cover. The rodents lived under the mat and destroyed the plants.

In terms of the harvest, timing of harvest is critical. Nut thieves- squirrels and chipmunks can be a problem near woods. Mice can be a problem, as can blue jays, woodpeckers, and bears. If you have only a few bushes, theft can be serious, but the problem decreases as the planting gets larger. Mow grass short to discourage mice, and put up a pole for a hawk and owl roost to attract predators.

Harvesting:

As of the printing of this report there is no mechanized method of harvesting hybrid hazelnut bushes in Minnesota.

Hazelnuts fruit in clusters of 2 to 20. Harvesters are being developed but as to date all harvests are done by hand in Minnesota. The clusters need to be picked before the squirrels; mice and birds get to them. Pick the nut clusters when ripe but before they drop; they will hang on the bush about 2 weeks when ripe. Allow clusters to mature further for several days/weeks in shade, then thresh husks off. Small-scale machines for this have been developed. Plans are available from Badgersett Research Corporation. The nuts can be separated into size groups by using screens of different sizes.

To store, dry nuts quickly in their shells to below 10%; a grain dryer should work for large scale. Common dry storage is fine. Hazelnuts can be stored for about a year.

Nut Sizes:

Hazelnuts have a standard size grade scale for nuts in shell,

Small	< 13 mm
Medium	13-18 mm
Large	18-19.5 mm
Very Large	19.5-22 mm
Giant	> 22 mm

Another qualifier for nuts is their kernel to shell ratio. The higher the ratio the better. Currently Hybrid Hazelnuts tend to have great variation between plants, but tend to be between 30%-37% kernel.

Marketing:

While there are significant markets nationally and internationally for hazelnuts, there are no established wholesale markets in Minnesota. Wholesale prices fluctuate between 30 and 50 cents a pound on the West Coast. Local, in shell, direct marketing prices are around $3.00 a pound as of 2000. Some value-added products include chopped nuts; chocolate covered nuts, nut paste, and oil.

Credits

The information for this report is based on data gathered through a study funded by the Minnesota Legislative Commission on Minnesota Resources. The research was conducted at four Minnesota research sites from 1999 through 2001. Furthermore, as a part of the research 17 farmer participants from Central, Western and South West MN were enlisted to grow trial plots and share their observations. Also the advice of Philip Rutter of Badgersett Research Corporation who has been breeding hybrid hazelnuts for over twenty years is included.

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Result 4. Indigenous native perennial legumes

- Tables 1-3
- Manuscript 1. Dehaan et al., 2001. Evaluation of diversity among and within accessions of Illinois bundleflower. Crop Sci. (in review)
- Manuscript 2. Dehaan et al., 2001. Evaluation of diversity among accessions of false indigo. Crop Sci. (in review)

Table 1. Stand Counts of Indigenous Legumes at four on-farm sites in Minnesota.

Location	Date	Alfalfa	False Indigo	Illinois Bundleflower
		---- number of seedlings per square meter ----		
Handeen Farm - Montevideo				
Fall - frost seeded	6/26/00	8	0	0
Spring		76	4	24
Fall - frost seeded	6/22/01	20	0	0
Spring		44	0	0
Struxness Farm - Milan				
Fall - frost seeded	6/26/00	20	0	0
Spring		28	4	56
Fall - frost seeded	6/22/01	32	0	0
Spring		52	1	0
Dansburger - Wilson				
Spring - tilled	9/7/00	---	12	48
Spring - untilled		---	16	152
Spring - tilled	6/20/01	---	7	61
Spring - untilled		---	4	14
Lentz - Lake City				
Spring - clipped	9/29/00	---	8	20
Spring - unclipped		---	12	0
Spring - clipped	6/20/01	---	1	3
Spring - unclipped		---	0	0

Table 2. Mean and range of traits measured on false indigo accessions at two locations in Minnesota.

Date	Trait Description	Becker Mean	Becker Range	Saint Paul Mean	Saint Paul Range
July 1999	Biomass yield, dry matter basis (g plant^{-1})	342.6	129-576	265.7	51.2-571
Aug. 1999	Biomass yield, dry matter basis (g plant^{-1})	5937	53.3-1236	697.6	58.3-1515
Aug. 1999	Dry matter, whole plant (g kg^{-1})	472	343-579	436	367-481
July 1999	Leaf conc., dry matter basis (g kg^{-1})	486	413-548	510	432-566
Aug. 1999	Leaf conc., dry matter basis (g kg^{-1})	660	607-775	628	573-671
July 1999	Acid detergent fiber, leaf material (g kg^{-1})	222	193-249	220	204-233
Aug. 1999	Acid detergent fiber, whole plant (g kg^{-1}) ‡	388	345-412	374	328-421
July 1999	Crude protein, leaf material (g kg^{-1})	195	169-212	201	171-235
Aug. 1999	Crude protein, whole plant (g kg^{-1}) ‡	144	132-212	140	118-167
July 1999	Neutral detergent fiber, leaf material (g kg^{-1})	331	299-361	326	292-359
Aug. 1999	Neutral detergent fiber, whole plant (g kg^{-1}) ‡	543	479-576	540	479-575
Sept. 1999	Height of plants cut in July 1999 (cm)	69.8	46.0-90.3	67.1	41.8-87.8
Sept. 2000	Height of plants cut in July 1999 (cm)	89.0	62.7-117	138.5	106-176
Sept. 2000	Height of plants cut in August 1999 (cm)	77.6	20.0-97.6	129.9	91.4-186
Sept. 1999	Height of never-cut plants (cm)	117.9	63.8-153	113.8	64.5-171
Sept. 2000	Height of never-cut plants (cm)	---	---	151.6	108-214
Sept. 1999	Width of plants cut in July 1999 (cm)	92.5	61.0-118	81.6	55.0-109
Sept. 2000	Width of plants cut in July 1999 (cm)	120.9	69.6-166	166.2	88.0-242
Sept. 2000	Width of plants cut in August 1999 (cm)	86.7	15.0-105	129.9	91.4-186
Sept. 1999	Width of never cut plants (cm)	150.5	67.6-211	141.7	70.9-211
Sept. 2000	Width of never cut plants (cm)	---	---	196.5	67.2-287
June 1999	Longest stem from 1998 growth (cm)	80.4	46.0-132	66.5	39.3-93.5
Nov. 1999	Length of longest regrowth from July 1999 (cm)	---	---	61.0	27.6-86.0
Nov. 1999	Length of longest regrowth from Aug. 1999 (cm)	---	---	25.3	10.5-41.4
Nov. 1999	Length of longest new twig growth in 1999 (cm)	70.9	30.1-103	77.3	35.2-113
July 1999	Number of 1998 branches, 0-25 cm from base	3.0	1.2-5.7	2.9	1.1-4.1
July 1999	Number of 1998 stems originating from crown	3.4	1.6-5.2	5.4	2.5-8.6
May 1999	Longest new growth of the season (cm)	11.6	8.4-15.2	4.6	1.5-8.4
June 1999	Growth stage	60	39-66	61	37-66
Sept. 1999	Growth stage	80	79-83	80	79-87
Oct. 1998	Leaf drop rating (1=0%, 5=100% dropped)	---	---	3.8	1.3-5.0
Oct. 1999	Leaf drop rating, never cut plants (1=0%, 5=100%)	4.7	3.6-5.0	4.0	1.2-5.0
July 1999	Dieback due to winter injury (length of dead twig)	10.6	4.7-47.2	13.3	5.3-66.2

July 1998	Potato leafhopper injury rating (1=none, 5=severe)	2.9	2.1-4.1	3.2	2.3-4.3
Sept. 1999	Potato leafhopper injury rating (1=none, 5=severe)	2.8	1.8-3.7	3.2	1.2-4.7
July 1999	Area of three leaves (cm^3)	149.2	85.2-202	119.0	60.1-156
July 1999	Leaf length, sum of three leaves (cm)	41.6	28.5-51.4	35.6	21.3-45.3
July 1999	Leaflet length, sum of three leaflets (cm)	10.6	8.4-12.8	9.6	7.5-10.9
July 1999	Leaflet width, sum of three leaflets (cm)	4.0	3.2-4.9	4.0	3.3-4.9
July 1999	Number of leaflets per 3 leaves	55.8	42.6-68.3	48.4	34.3-61.0
July 1999	Average number of racemes per cluster	3.0	2.0-3.6	2.9	1.9-4.1
July 1999	Number of flower clusters, rating (1=0, 5>45)	2.2	1.0-4.1	2.6	1.0-4.6
July 1999	Shortest raceme in a cluster (cm)	5.3	2.4-8.1	5.2	3.0-8.4
July 1999	Longest raceme in a cluster (cm)	8.0	5.2-11.9	8.1	4.9-11.5

Table 3. Mean and range of traits measured on Illinois bundleflower accessions at two locations in Minnesota.

		Becker		Saint Paul	
Date	**Trait Description**	**Mean**	**Range**	**Mean**	**Range**
July 1999	Biomass yield (g plant-1)	138.3	82.8-181	78.8	27.9-139
Aug. 1999	Biomass yield (g plant-1)	394.7	295-495	283.0	108-456
July 1999	Forage acid detergent fiber (g kg-1)	319	285-351	258	214-302
Aug. 1999	Forage acid detergent fiber (g kg-1)	444	415-480	393	335-427
July 1999	Forage neutral detergent fiber (g kg-1)	364	333-409	311	263-359
Aug. 1999	Forage neutral detergent fiber (g kg-1)	493	444-535	436	333-501
July 1999	Forage crude protein (g kg-1)	168	151-190	192	166-236
Aug. 1999	Forage crude protein (g kg-1)	119	106-133	150	125-175
July 1999	Forage leaf concentration (g kg-1)	587	543-686	699	628-750
Aug. 1999	Forage leaf concentration (g kg-1)	200	128-310	311	159-454
Aug. 1999	Forage stem concentration (g kg-1)	370	278-484	405	305-561
Aug. 1999	Forage pod concentration (g kg-1)	430	205-540	302	63.4-513
1998	Seed yield (g plant-1)	34.4	8.12-61.0	52.8	9.78-99.5
1999	Seed yield (g plant-1)	70.6	42.4-97.1	59.2	32.7-108
2000	Seed yield (g plant-1)	72.8	29.7-130	54.9	24.3-108
1998	Seed weight (g 200 seeds-1)	6.66	5.79-7.47	5.77	4.59-6.52
1999	Seed weight (g 200 seeds-1)	5.52	4.96-6.17	5.62	4.76-6.28
2000	Seed weight (g 200 seeds-1)	5.69	4.93-5.98	5.94	5.21-6.28
1998	Seed crude protein	33.7	29.9-36.3	35.0	31.4-37.6
1999	Seed crude protein	30.2	28.2-33.2	32.1	30.5-33.8
2000	Seed crude protein	32.3	30.1-34.5	35.1	33.3-37.1
1998	Growth stage	2.73	1.10-4.03	1.99	1.07-3.24
June 1999	Growth stage	333.5	47.3-666	132.3	34.9-264
Sept. 1999	Growth stage	344.2	51.1-612	140.0	29.9-259
Sept. 1999	Height of never-cut plants (cm)	115.5	56.5-167	94.2	69.3-107
Sept. 1999	Height of plants cut in July, 1999 (cm)	58.8	37.9-80.0	62.9	26.0-100
Sept. 2000	Height of never-cut plants (cm)	91.2	47.1-117	106.5	67.8-125
Sept. 2000	Height of plants cut in July, 1999 (cm)	97.6	50.5-138	110.0	58.0-160
Sept. 1999	Width of never-cut plants (cm)	144.9	116-183	137.7	105-164
Sept. 1999	Width of plants cut in July, 1999 (cm)	77.9	63.9-93.3	82.8	26.0-152
Sept. 2000	Width of never-cut plants (cm)	147.8	95.8-181	138.9	93.5-185
Sept. 2000	Width of plants cut in July, 1999 (cm)	152.5	111-181	149.2	102-195
1998	Stem length (cm)	60.6	19.8-91.0	---	---
1999	Stem length of never cut plants (cm)	121.9	84.5-175	108.7	93.7-125
1999	Stem length of plant cut in July, 1999	64.3	46.6-94.2	68.0	28.0-108
1999	Number of stems	13.5	6.35-17.5	9.66	5.64-12.8

1999	Leaf length (cm)	24.0	18.2-28.6	26.0	22.4-28.7
1999	Leaf width (cm)	21.5	17.6-25.2	23.9	20.5-26.5
1999	Number of pinnae	77.8	65.3-92.7	71.6	53.9-79.2
Aug. 1998	Plant vigor rating (0=dead, 3=vigorous)	1.38	1.00-3.00	1.35	1.00-3.00
Sept. 2000	Survival never harvested plants	---	---	0.68	0.13-0.97
Sept. 2000	Survival harvested plants inn July	0.43	0.00-0.88	0.91	0.60-1.00
Sept. 2000	Survival harvested plants in August	0.02	0.00-0.11	0.22	0.00-1.00
Sept. 2000	Survival, never harvested plants	0.63	0.16-0.88	0.56	0.07-0.95

Evaluation of Diversity Among Accessions of False Indigo

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ABSTRACT

False indigo (*Amorpha fruticosa* L.) is a perennial leguminous shrub native to North America. The species could potentially be used in the Upper Midwest for livestock forage, biomass energy, reclamation of degraded environments, or as a source of N-rich green manure. Studies of these potential uses and plant breeding efforts with the species both depend upon knowledge of available accessions. Our objectives were to 1) determine the range of genetically controlled diversity present between false indigo accessions, 2) determine the patterns of variation between false indigo accessions, and 3) examine the relationships between traits in false indigo. We studied 21 accessions at 2 locations and 15 accessions at a third location. We measured 47 morphological, agronomic, and phonological traits. All traits were influenced by accession in at least one environment ($p<0.05$). Biomass yield varied widely by accession and accession mean biomass yield was correlated across locations. False indigo had a high leaf concentration, averaging 660 g kg^{-1} dry matter (DM) at one location in August. Forage quality of false indigo leaves was high, with average crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) concentrations in July of 205, 226, and 235 g kg^{-1}, respectively. Accession means of forage quality traits were poorly correlated across environments, indicating that they would be difficult to improve through selection. The most productive false indigo accessions have potential to produce high leaf and biomass yields under a single annual cutting management. Our results indicate that false indigo could supply summer forage and serve as a biomass energy crop.

False indigo is a perennial leguminous shrub native to North America. A mature plant has a broad crown with 1 to 10 stems growing to a height of 1.0 to 3.5 m. The native range of the species extends from southern Canada to northern Mexico, and west to California (Allen and Allen, 1981). The specie's natural habitats include open wet woods, shores of ponds, moist ground near streams, rocky banks, and ravines (Great Plains Flora Association, 1986). False indigo is highly variable in morphology, evidenced by the fact that the species has been assigned at least 16 synonyms (Simpson, 1989). False indigo is capable of symbiotic N_2 fixation (Allen and Allen, 1981). Wang et al. (1999) have identified the primary N_2-fixing bacteria (*Mesorhizobium amorphae*) as a unique species.

False indigo has been described botanically by Wilbur (1975). The pinnately compound leaves are 10-28 cm long with 9-21 leaflets that are 2-4 cm long and 1-2 cm wide. Flowers are in clusters of racemes that are 5-20 cm long. The single petal is 5-6 mm long and is wrapped around a single pistil and 10 stamens that are 6-8 mm long. The fruit is a indehiscent legume that contains a single seed 3.5-4.5 mm long and 1.5 mm wide. The chromosome number is 2n=40, double the number of the closely related species *Amorpha canescens* Pursh (Great Plains Flora Association, 1986). Therefore, false indigo is most likely a hexaploid. Flower structure and attractiveness to bees (Holmes, 1985) indicate that false indigo is primarily cross-pollinated.

Research with false indigo in the Mediterranean region has demonstrated its potential for use in pastures. False indigo has good forage quality (Papachristou and Papanastasis, 1994) and has produced up to 62% grazable material (Platis and Papanastasis, 1993). It is tolerant of defoliation and capable of regrowing to a height of 1 m after annual cutting to 10 cm for 7 yr (Papanastasis et al., 1998). False indigo was not a preferred fodder of goats (*Capra hircus* L.) in

July, but goats consuming it in September gained weight at a rate similar rate to that of goats being fed alfalfa (Papachristou et al., 1999).

False indigo is being adopted by farmers in France, where more than 30 ha of false indigo were planted for use as forage in 1996 and 1997 (Dupraz, 1999). Because the species has low palatability to goats (Papachristou and Papanastasis, 1994), its adoption by farmers is surprising. Durpaz (1999) concluded that farmers find less palatable shrubs to be easier to manage. When livestock does not prefer the shrub, stockpiling its leaf material for summer consumption is facilitated. In addition, preventing extinction due to overgrazing is easier to achieve

False indigo has potential to enhance the productivity and forage quality of temperate grasslands. Although an objective of grassland management is often to prevent invasion by woody plants, there are numerous examples of shrub species used for forage. In Europe, woody plants are becoming an integral part of grasslands (Papanastasis, 1999). The shrub fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) interseeded in a semiarid pasture increased the amount and quality of forage produced (Rumbaugh, etl al., 1982). Establishing the woody plant *Leucaena leucocephala* (Lam.) de Wit in tropical pastures provides the benefits of increased forage production, increased protein content of the forage, N_2 fixation, and wood for fuel (Murethi, 1995). In Australia, shrubs are widely used as a late-season fodder source (Lefroy, 1994). Winterfat (*Krascheninnikovia lanata* (Pursh) A. Meeuse & A. Smit) and antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) are two highly desirable shrub species in North Amercian rangeland (Romo 1995; Ganskopp, 1999).

In the upper Midwest, cool season pasture species are most productive in the spring and fall, which causes shortages of available forage in grazing systems during the summer months. Warm season grasses have been helpful in providing forage during the summer months. Because the currently used cool-season legume species are not compatible with the warm season grasses, warm season grass pastures have not had the benefits that are derived from including a legume component (Marten, 1985). False indigo has potential to function as a legume component in warm season-grass pastures because of its capability of producing forage during hot, dry summer months (Ainalis and Tsiouvaras, 1998).

False indigo is also a potential biomass energy crop. In a study of 107 legumes for renewable energy sources, false indigo ranked in the top 11 (Roth et al., 1984). At St. Paul, MN, a pure stand of false indigo cut annually for five years had an average biomass yield of 11.3 Mg ha^{-1} yr^{-1} with no sign of decreasing productivity (E. Ristau, personal communication, 2001). False indigo may be most useful in a biomass energy system similar to that proposed for alfalfa (*Medicago sativa* L.) where stems would be used to generate electricity and leaves would be used as a high protein livestock feed (Sheaffer et al., 2000). False indigo is a good candidate species for use in this system because of the large biomass yields obtained with a single harvest and because the crude protein content of leaves harvested in August has been up to 240 g kg^{-1} (E. Ristau, personal communication, 1997). A biomass energy system using false indigo could have a cost advantage compared to alfalfa due to fewer harvests needed and because of the potential to eliminate the need for mechanical fractionation of leaf and stem portions. Livestock could be used to graze the leaves directly, and stems could be harvested on an annual or biennial basis.

There is a diversity of other uses for false indigo. In China, plants are used for erosion control, wildlife food, green manure, and the seeds are used as an oil source in the manufacture of glycerol (Wang et al., 1999). Its vigorous growth on poor soil makes it an excellent species for use in reclamation of degraded environments (Brown, et al., 1983). The pods (Brett, 1946) and leaves (Cao, 1996) contain natural insecticides. Chemicals isolated from the leaves of false indigo have demonstrated extremely high anti-tumor promoting activities (Konoshima et al. 1993). Because of its spring flower display, false indigo is also used horticulturally (Simpson et al., 1989).

False indigo has potential to be a multiple-use, long-lived perennial legume on Upper Midwestern landscapes. Studies are needed to investigate the diversity of potential uses for the plant. However, agronomic experiments will be of little value with no prior knowledge of the genetic material being used. Wilbur (1975) has indicated that false indigo is an extremely diverse species, but that the variation is due to both environmental plasticity and genetic diversity. Our objectives were to 1) determine the range of genetically controlled diversity present between false indigo accessions, 2) determine the patterns of variation between false indigo accessions grown in three diverse environments and 3) examine the relationships between traits in false indigo. Priority was given to traits that would be most important in grazing or biomass energy systems.

MATERIALS AND METHODS

Seeds of 21 false indigo accessions were obtained from throughout North America, with most originating from the northern range of the species (Table 1). Many of the accessions were collected from wild populations using information from the Minnesota Vascular Plant Database (Univ. of Minnesota Herbarium, 2001). Four accessions were obtained from the National Plant Germplasm System (USDA, ARS, 2001).

The accessions were established in randomized complete block experiments at three locations: St. Paul, MN; Becker, MN; and Sioux Center, IA. At St. Paul there were five replications and six plants plot^{-1}, at Becker there were 10 replications and 6 plants plot^{-1}, and at Sioux Center there were seven replications and seven plants plot^{-1}. The soil at St. Paul was a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll) with pH, P, K, and organic matter levels of 7.6, 291 kg ha^{-1}, 503 kg ha^{-1}, and 32 g ha^{-1}. The soil at Becker was a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) with pH, P, K, and organic matter levels of 7.3, 88 kg ha^{-1}, 165 kg ha^{-1}, and 18 g ha^{-1}. The soil at Sioux Center was a Galva silty clay loam (fine-silty, mixed, superactive, mesic Typic Hapludoll) with pH, P, K, and organic matter levels of 7.2, 224 kg ha^{-1}, 672 kg ha^{-1}, and 61 g ha^{-1}. Due to limited seed supply, only entries 1-15 were established at Sioux Center and seed of entries 17-21 was only adequate for 2-3 plants plot^{-1} at St. Paul and Becker.

Seeds were scarified with sandpaper and planted in 4 by 20.5 cm cones in the greenhouse in early April 1998. The containers were surface-inoculated with appropriate rhizobium (LiphaTech, Milwaukee, WI 53209) after planting. At all locations, plants were spaced 1.52 m apart in rows 3.04 m apart. At St. Paul and Sioux Center, the space between rows was regularly mowed. At Becker, soil between the rows was regularly tilled. Weeds within the rows were controlled with imazapic {(±)-2-[4,5-dihydro-4-methyl-4(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} and pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] herbicides and hand weeding. At Becker, irrigation was provided according to the checkbook method (Wright and Bergsrud, 1991) in 1998 and 1999, but not in 2000. Potato leafhoppers (*Empoasca fabae* Harris) were controlled with permethrin [cyclopropanecarboxylic acid, 3-(2,2-dichloroethenyl)2,2-dimethyl-(3-phenoxyphenyl)methyl ester] insecticide at Becker and St. Paul. Treatments were applied twice in 1998 and five times in 1999.

We measured 47 traits (Table 2). Many traits were measured on every plant in each plot. Biomass yield, forage quality, and percent leaf were determined by cutting one plant $plot^{-1}$ to a height of 10 cm in mid July 1999 and cutting a second plant in each plot in mid August. Plants cut in July at St. Paul and Becker and in both months at Sioux Center were dried before separating and weighing leaf and stem fractions. Only the leaf fraction of these samples was used in subsequent forage quality analysis. Whole plants harvested in August at Becker and St. Paul were passed through a chipper and weighed. A subsample was dried at 60° C for 48 hours and weighed to calculate percent dry matter content and was subsequently used for forage quality analysis.

Growth staging was performed using a modified version of the approach of Lancashire et al. (1991). Because the staging codes are not linear, we converted the codes to ranks before performing statistical calculations. To aid interpretation, the values presented in Table 2 were obtained by converting from ranks back to the growth stage code.

Forage Quality Analysis

Forage CP, NDF, ADF (Goering and Van Soest, 1970), and leaf concentration of the forage were determined using near infrared reflectance spectroscopy (NIRS). A 500-g subsample of the forage harvested from each plant in July and August 1999 was ground in a cyclone mill with a 1 mm screen. The samples were tumbled in a drum turning at 15 rpm for 20 min to obtain homogeneity. Spectra were collected on all samples using a NIRS scanning monochromomator, model 6500 (Foss North America, Inc., Eden Prairie, MN 55344) and NIRS version 4.0 software (Infrasoft International, Port Matilda, PA 16870). Reflectance data were recorded between 400 and 2500 nm wavelengths at 2-nm intervals. Reference procedures were performed on samples selected by the software and prediction equations were developed. An equation for percent leaf was developed by using 47 samples that were hand separated, weighed, ground, and reconstituted. The 1-VR values for the prediction equations were 0.97, 0.99, 0.98, and 0.87 for CP, NDF, ADF, and percent leaf, respectively.

Statistical Analysis

Mean, maximum, and minimum values of every entry were calculated for each trait in every environment to assess the range and distribution of values for each trait. A weighted analysis of variance (ANOVA) was performed on plot means of every trait for each environment in which it was measured. The numbers of individuals measured per plot were used as weights. Traits that were not influenced by entry ($P<0.05$) were excluded from further analysis. For all other traits, adjusted means were calculated for each entry.

Cluster analysis was performed using all entries and all traits that were influenced by entry. First, adjusted accession means of each trait were standardized by subtracting the trait mean and dividing by the standard deviation. Then the average taxonomic distance between all accessions was calculated and the resulting distance matrix was used to generate a tree using the WPGMA (weighted pair-group method, arithmetic averages) clustering procedure. An average taxonomic distance of 1.08 was arbitrarily selected to divide the entries into seven clusters.

A principal component (PC) analysis was performed on standardized ((accession mean - trait mean) / standard deviation) adjusted means using only the most agronomically important traits (listed in Table 3). Entries 19 and 20 were excluded because their distinctiveness masked differences between the remaining populations which were of more northern origin and therefore of primary interest. Data from Sioux Center was excluded from the analysis because this location did not include populations 16-21 and therefore would have made the analysis difficult to interpret. Correlations between the first four PCs and the initial traits were calculated to aid in interpretation of the analysis.

A correlation analysis between selected agronomic traits was performed using Spearman-rank correlations. The ANOVA and correlation analyses were performed with SAS software (SAS Institute, 1990), and PC and cluster analyses were performed with NTSYSpc (Rohlf, 2000).

RESULTS AND DISCUSSION

All traits measured at Becker were influenced by accession (Table 2). At St. Paul, all measured traits were influenced by accession except forage quality traits for the July biomass harvest and percent leaf from the August biomass harvest. At Sioux Center, 20 of the 29 measured traits were influenced by accession. These results indicate that the false indigo accessions we evaluated contain substantial genetic diversity for agronomic and morphological traits.

The range of biomass yield in August was about 200% of the mean, which is similar to the range found between 1,100 perennial *Medicago* plant introductions (Basigalup, et al., 1995). The very wide range in biomass yield points to the importance of selecting accessions for further study based upon their biomass yield. Average August biomass yield at Becker and St. Paul increased over July biomass yield by 73 and 163%, respectively, indicating potential of this species to produce forage in the summer months. Unlike cool season forages, the majority of false indigo biomass production occurs in the hot summer months.

Comparing the biomass yield of the most productive false indigo accessions to other species would be useful in considering potential uses for the species. Due to the low planting density of the present study (2164 plants ha^{-1}), single plant yields cannot be used as a meaningful estimate of yield in a pure stand. However, we do know that Entry 13 yielded 11.3 Mg ha^{-1} in a pure stand (10,000 plants ha^{-1}) over five years of annual cutting. If plant population by entry interactions are assumed to minor, we can estimate biomass yield of other accessions by comparing them to Entry 13. Because Entry 13 as not the highest yielding accession at any of the locations, we conclude that selection for biomass yield enable biomass yields greater than 11.3 Mg ha^{-1}. Entry 14, which was consistently high yielding across all three locations, had an August biomass yield that exceeded that of Entry 13 by 25.7% ($p<0.05$) at St. Paul. In a pure stand, we would expect entry 14 to have an annual biomass yield of 14.2 Mg ha^{-1}.

At Becker and St. Paul, leaf concentration increased dramatically from July to August. The average August leaf concentrations of 660 and 628 g kg^{-1} DM at Becker and St. Paul, respectively, point to the potential of this species to produce leafy forage when harvested at the appropriate time. For comparison, alfalfa leaf concentration is about 580 g kg^{-1} DM in the late vegetative state, and declines rapidly to 410 g kg^{-1} DM at the early pod stage (Marten et al. 1988). Alfalfa requires multiple cuts per year to obtain maximum leaf concentration, but high leaf concentrations can be obtained with a single annual cutting of false indigo. Entry 13 grown at 10,000 plants ha^{-1} and harvested in June had a leaf concentration of 800 g kg^{-1} DM (E. Ristau, personal communication, 1996), indicating that false indigo can maintain a high leaf concentration even at a higher planting density. Using estimates that false indigo has a potential annual biomass yield 11.3 Mg ha^{-1} and a leaf concentration of 640 g kg^{-1} DM, false indigo leaf yield will be 7.23 Mg ha^{-1}. With a CP concentration of 200 g kg^{-1}, total CP yield in false indigo leaves will be 1.45 Mg ha^{-1}. Maximum leaf CP yield in alfalfa under an optimal three-harvest management is about 1.46 Mg ha^{-1} (Sheaffer et al., 2000; Kuehn et al., 1999). We conclude that the highest yielding false indigo accessions harvested annually have potential to produce a leaf CP yield equivalent to intensively managed alfalfa.

The variation among accessions for forage quality traits (CP, NDF, ADF) was low but often significant (Table 2). Averaged across locations and entries, false indigo had July-harvested leaf ADF and NDF concentrations of 226 and 335 g kg^{-1}, respectively. These values are similar to those for leaves of moderate quality alfalfa hay (RFV=87-124) (Kuehn et al., 1999). Average CP concentration of July-harvested false indigo leaves was 205 g kg^{-1}, less than the CP concentration of alfalfa leaves alone, but similar to the CP concentration of prime alfalfa hay (Kuehn et al., 1999). On a whole plant basis, August-harvested false indigo had average ADF and NDF concentrations of 381 and 542 g kg^{-1} DM, respectively. These concentrations are similar to those of average quality alfalfa hay (Kuehn et al., 1999). Average whole plant CP concentration from the August harvest was 140 g kg^{-1} DM, similar to low quality alfalfa hay (Kuehn et al., 1999). Recent work by Parissi and Nastis (1999) demonstrated that oven drying false indigo forage could result in NDF concentrations being overestimated by more than 10%. Therefore, the values determined in this experiment may be underestimating the forage quality of false indigo.

Location influenced many traits, particularly those related to plant size (Table 2). Plants at Sioux Center were generally smaller than those at the other two locations. A probable explanation of this trend is that false indigo is poorly adapted to heavier clay soil such as that at Sioux Center. This reasoning is supported by the observation that all of our collections were made from locations with sandy or stony soils.

Differences in potato leafhopper injury were striking, indicating that potato leafhopper resistance will be an important trait in future selection programs. Even the most resistant accessions sustained some injury, despite insecticide applications.

Accessions differed widely in their extent of winter injury, but the most severe winter injury occurred only on entries 19 and 20 from the southern United States. Although these accessions had severe dieback, the plants were never killed. Average winter injury was small at Sioux Center because the southern accessions were not planted at this location.

Morphological traits such as leaf size and shape varied widely, which is consistent with the observation that variable leaf morphology is the source of taxonomic confusion with this species (Great Plains Flora Association, 1986). The number and size of inflorescences also varied by accession, which could be important for horticultural use and seed production.

Phenological traits varied substantially by accession (Table 2). In June 1999, the latest maturing accessions at Becker and St. Paul were still in a vegetative state while the earliest maturing accessions were in full flower. At Sioux Center, all accessions were, on average, in a vegetative state because few plants at this location flowered in 1999. In September 1999 growth staging was only performed on plants that had set fruit. At Becker and St. Paul the latest maturing accessions had fruit that had not yet started to ripen. At Becker, the most mature accessions had some ripe fruit and at St. Paul the most mature accessions had fruit that was near to being fully ripe. Timing of late season leaf drop, another phonological trait, also varied by accession. Increasing late season leaf retention could be an important means to enhance stockpiling for late summer grazing.

Cluster and Principal Component Analysis

Cluster analysis (Fig. 1) provided an accurate grouping of the accessions (cophenetic correlation=0.803). The clusters were generally representative of distinct geographical regions. Cluster 1 accessions originated from central to west central Minnesota. Cluster 2 accessions were from southwest Minnesota, northwest Iowa, and South Dakota. Cluster 3 contained a single accession that probably originated from Ontario, Canada. Cluster 4 consisted of 2 accessions of unknown origin and a third accession from Idaho. Cluster 5 contained two accessions from northwest Minnesota and, surprisingly, one accession from southeast Minnesota. Clusters 6 and 7 each contained a single accession originating from the southern United States. Although these accessions were distinctly different from all other accessions (average taxonomic distance=1.96), they were also distinct from each other. The general agreement of cluster analysis with geographic origin indicates that obtaining additional accessions from other regions could substantially increase the diversity available for use in plant breeding.

The first four PCs explained 52, 13, 11, and 5% of the variance, respectively. In total, the first four PCs explained 81% of the variance. Most traits were correlated (r>0.60 or r<-0.60) with at least one of the PCs (Table 3).

Clusters 1-5 were clearly separated by the first two PCs (Fig. 2), indicating that the clusters represent similarities and differences between accessions that are correlated with PCs 1 and 2 (Table 3). The position of the clusters on the plot of the first two PCs can therefore be used to infer relative values for many traits. For instance, Cluster 4 is comprised of accessions that were tall, wide, high biomass yielding, and had many flowers. Cluster 1 is comprised of accessions with low biomass yield, large leaves, and susceptibility to potato leafhoppers. Accessions in Cluster 5 had low biomass yield, low leaf percent at St. Paul in July and low forage quality in July at Becker. Accessions in Clusters 2 and 3 were intermediate for the majority of traits used in the PC analysis.

Biomass yield, June growth stage, leaf drop, and plant size measurements were generally well correlated with the first PC, regardless of harvest date or location. Growth stage in June was positively correlated with PC1, but October leaf drop was negatively correlated with PC1. Because biomass yield was positively correlated with PC1, we conclude that the highest yielding accessions tend to flower early and do not drop their leaves until late in the season. Therefore, increased biomass yield and leaf retention should be compatible plant breeding objectives.

Forage quality traits were correlated with the second, third, or fourth PC, depending upon harvest date and location. Lack of correlation with a single PC indicates that forage quality of false indigo accessions is not consistent across harvest dates and locations. This observation was further examined in the correlation analysis.

Principal components 3 and 4 are most highly correlated with traits relating to maturity, winter injury, regrowth after August cutting, and August forage quality (Table 3). In general, accessions with low values for PC 3 had high forage quality at St. Paul and accessions with high values for PC 4 had high forage quality at Becker. Principal components 3 and 4 clearly separate Entry 18 from all other accessions (Fig. 3), indicating that this entry was placed in a unique cluster largely because of its distinctiveness for traits highly correlated with PCs 3 and 4.

Correlation Analysis

For both July and August harvests, biomass yields of false indigo accessions were correlated across locations (Tables 4 and 5), indicating that relative biomass productivity of the accessions was fairly stable across environments. Growth stage in June was correlated across locations was also correlated with biomass yield across locations. The consistent association between June growth stage and biomass yield across diverse environments indicates that early flowering may be a good predictor of high biomass yield.

The correlations of percent leaf with CP and NDF were low, even for the August harvest (Table 5). This result is surprising because the August forage quality analysis included both leaves and stems. Given that woody stems are expected to have low forage quality and that percent leaf varied among accessions, we expected CP and NDF to be strongly influenced by percent leaf. A possible explanation for the result we obtained is that the CP and NDF of the leaf and/or stem components separately varied widely in August, thereby overwhelming the influence of percent leaf on these traits. Biomass yield was sometimes negatively correlated with CP and sometimes positively correlated with NDF, but the relationships were weak. Therefore selection for increased biomass yield will not necessarily reduce forage quality.

The correlations between CP across locations and NDF across locations were generally low. The low correlations indicate that the forage quality of some accessions was not consistent across environments. In alfalfa (*Medicago sativa* L.) Sheaffer et al., (1998) found that some alfalfa varieties had stable forage quality across locations, while others were variable. An examination of the mean CP and NDF values (data not shown) indicated that several false indigo accessions had more stable forage quality across environments than others. These results indicate that selection for forage quality in false indigo could be difficult and that it must be performed in multiple environments.

CONCLUSIONS

False indigo accessions vary widely in their potential for biomass yield and biomass yields of accessions in diverse environments were correlated. Therefore, selection for increased biomass yield is likely to produce rapid increases. Late season leaf retention and early flowering were correlated with biomass yield. Selection for these traits will provide the benefits of increased yield and enhanced capability of stockpiling forage. Variation for resistance to leafhopper injury exists among accessions, and selection for resistance will be critical to high forage yields. False indigo was most productive during the summer months, indicating that it is likely to be compatible with warm season grasses and would be a good source of summer forage. Biomass yields of false indigo were low on silty clay loam soil, indicating that the species is poorly adapted to heavy soils.

False indigo biomass has a very high leaf concentration when compared to alfalfa. Values of ADF, NDF, and CP obtained in this study substantiate previous work that found false indigo to be a nutritious fodder species (Papachristou and Papanastasis, 1994). Because false indigo has potential to produce high leaf and total biomass yields under a single annual cutting management, it is a promising species for use in a combined forage and biomass energy system.

Forage quality of false indigo accessions was not consistent across locations. Therefore, selection for forage quality traits would be difficult and would have to be performed in multiple environments. Forage quality traits were generally not negatively correlated with biomass yield, indication that selection for increased biomass yield would not be likely to reduce forage quality.

Cluster analysis of false indigo accessions indicated that diversity among false indigo accessions is often consistent with the geographic origin of the accessions. Obtaining new accessions from a wider geographical range would increase the genetic diversity available to a plant breeding program. The two southern accessions included in the study were distinct from all other accessions which indicates that substantial genetic diversity could be introduced by crossing northern and southern accessions.

The present study has provided a wealth of information on the performance of 21 false indigo accessions in three environments. Accession means of each trait can be accessed online at www.falseindigo.edu. Future work should include studies of optimal management of the most promising accessions and an evaluation of diverse accessions for palatability to livestock.

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Table 1. False indigo accession information.

Entry	Accession†	Accession Details
1	PNL468	Buffalo, Wright Co., MN, north shore of Buffalo Lake
2	PNL469	Annandale, Wright Co., MN, east shore of Pleasant Lake
3	PNL470	Annandale, Wright Co., MN, east shore of Clearwater Lake
4	PNL471	Hawley, Clay Co., MN, northeast shore of Silver Lake
5	PNL472	Melby, Douglas Co., MN, east shore of Lake Christina
6	PNL473	Hitterdal, Clay Co., MN, east shore of Swede Grove Lake
7	PNL474	Syre, Norman Co., MN, north shore of Home Lake
8	PNL475	Lake Crystal, Blue Earth Co., MN, east shore of Lily Lake
9	PNL476	Avoca, Murray Co., MN, northeast shore of Lime Lake
10	PNL477	Rock Rapids, Lyon Co., IA, Island City Park
11	PNL322	Univ. of MN Landscape Arboretum, Chanhassen, MN
12	PNL410	Chelsea, Edmunds Co., SD, north shore of Middle Scatterwood Lake
13	PNL329	Prairie Moon Nursery, Winona, MN, seed increased by Univ. of MN
14	PNL127	Seed from single plant from Prairie Moon Nursery, Winona, MN
15	PNL131	Seed from single plant from Prairie Moon Nursery, Winona, MN
16	PNL479	St. Charles, Winona Co., MN, bank of Whitewater River
17	PI303182	Emett, Gem Co., ID, Payette River flood plain
18	PI372505	Ontario, Canada
19	PI436710	Caddo Co., OK
20	DLEG910517	Cochise Co., AZ, Along stream in conifer forest
21	PNL478	Mina, Edmunds Co., SD, Southeast shore of Mina Lake

†Accession origin: PNL=University of Minnesota Native Perennial Legume Collection and PI or DLEG=The USDA ARS National Plant Germplasm System.

Table 2. Traits measured on false indigo accessions at three locations, significance of accession effects, and range and mean of accession means.

			Becker			Saint Paul			Sioux Center		
Trait	**Date**	**Description**	**Entry**	**Mean**	**Range**	**Entry**	**Mean**	**Range**	**Entry**	**Mean**	**Range**
Bmsj	July 1999	Biomass yield, dry matter basis (g $plant^{-1}$)	***	342.6	129-576	***	265.7	51.2-571	ns	143.3	94.7-185
Bmsa	Aug. 1999	Biomass yield, dry matter basis (g $plant^{-1}$)	***	5937	53.3-1236	***	697.6	58.3-1515	***	208.7	120-337
DM	Aug. 1999	Dry matter, whole plant (g kg^{-1})	***	472	343-579	**	436	367-481	--†		
LFj	July 1999	Leaf conc., dry matter basis (g kg^{-1})	***	486	413-548	*	510	432-566	ns	629	600-668
LFa	Aug. 1999	Leaf conc., dry matter basis (g kg^{-1})	**	660	607-775	ns	628	573-671	*	630	563-675
ADFj	July 1999	Acid detergent fiber, leaf material (g kg^{-1})	***	222	193-249	ns	220	204-233	***	235	221-250
ADFa	Aug. 1999	Acid detergent fiber, whole plant (g kg^{-1}) ‡	***	388	345-412	***	374	328-421	ns	223	209-245
CPj	July 1999	Crude protein, leaf material (g kg^{-1})	***	195	169-212	ns	201	171-235	**	220	208-232
CPa	Aug. 1999	Crude protein, whole plant (g kg^{-1}) ‡	***	144	132-212	***	140	118-167	ns	209	186-219
NDFj	July 1999	Neutral detergent fiber, leaf material (g kg^{-1})	***	331	299-361	ns	326	292-359	***	348	328-386
NDFa	Aug. 1999	Neutral detergent fiber, whole plant (g kg^{-1}) ‡	***	543	479-576	*	540	479-575	ns	331	317-355
Ht98	Oct. 1998	Plant height (cm)	--			--			***	26.9	11.2-37.4
Ht99j	Sept. 1999	Height of plants cut in July 1999 (cm)	***	69.8	46.0-90.3	***	67.1	41.8-87.8	--		
Ht00j	Sept. 2000	Height of plants cut in July 1999 (cm)	***	89.0	62.7-117	***	138.5	106-176	--		
Ht00a	Sept. 2000	Height of plants cut in August 1999 (cm)	***	77.6	20.0-97.6	***	129.9	91.4-186	--		

Ht99n	Sept. 1999	Height of never-cut plants (cm)	***	117.9	63.8-153	***	113.8	64.5-171	--		
Ht00n	Sept. 2000	Height of never-cut plants (cm)	--			***	151.6	108-214	--		
Wd99j	Sept. 1999	Width of plants cut in July 1999 (cm)	***	92.5	61.0-118	***	81.6	55.0-109	--		
Wd00j	Sept. 2000	Width of plants cut in July 1999 (cm)	***	120.9	69.6-166	***	166.2	88.0-242	--		
Wd00a	Sept. 2000	Width of plants cut in August 1999 (cm)	***	86.7	15.0-105	***	129.9	91.4-186	--		
Wd99n	Sept. 1999	Width of never cut plants (cm)	***	150.5	67.6-211	***	141.7	70.9-211	--		
Wd00n	Sept. 2000	Width of never cut plants (cm)	--			***	196.5	67.2-287	--		
LngSt98	June 1999	Longest stem from 1998 growth (cm)	***	80.4	46.0-132	***	66.5	39.3-93.5	***	30.4	9.7-51.3
NGr99j	Nov. 1999	Length of longest regrowth from July 1999 (cm)	--			***	61.0	27.6-86.0	ns	40.2	26.5-48.9
NGr99a	Nov. 1999	Length of longest regrowth from Aug. 1999 (cm)	--			***	25.3	10.5-41.4	ns	26.9	19.5-41.1
NGr99n	Nov. 1999	Length of longest new twig growth in 1999 (cm)	***	70.9	30.1-103	***	77.3	35.2-113	***	50.6	23.9-75.1
NbBrc98	July 1999	Number of 1998 branches, 0-25 cm from base	***	3.0	1.2-5.7	***	2.9	1.1-4.1	***	1.6	0.3-2.8
CrStm98	July 1999	Number of 1998 stems originating from crown	***	3.4	1.6-5.2	***	5.4	2.5-8.6	***	1.6	1.1-2.0
BkStm	all 1999	Number of stems per plant broken by wind	***	0.2	0.0-1.0	--			--		
ErGr99	May 1999	Longest new growth of the season (cm)	***	11.6	8.4-15.2	***	4.6	1.5-8.4	***	2.8	1.8-4.6
GS199	June 1999	Growth stage	***	60	39-66	***	61	37-66	***	39	38-39
GS299	Sept. 1999	Growth stage	***	80	79-83	***	80	79-87	--		
LfDr98	Oct. 1998	Leaf drop rating (1=0%, 5=100% dropped)	--			***	3.8	1.3-5.0	--		
LfDr99n	Oct. 1999	Leaf drop rating, never cut plants (1=0%, 5=100%)	***	4.7	3.6-5.0	***	4.0	1.2-5.0	--		

WInj99	July 1999	Dieback due to winter injury (length of dead twig)	***	10.6	4.7-47.2	***	13.3	5.3-66.2	***	3.8	1.5-5.3
Hop98	July 1998	Potato leafhopper injury rating (1=none, 5=severe)	***	2.9	2.1-4.1	***	3.2	2.3-4.3	--		
Hop99	Sept. 1999	Potato leafhopper injury rating (1=none, 5=severe)	***	2.8	1.8-3.7	***	3.2	1.2-4.7	--		
LfArea	July 1999	Area of three leaves (cm^3)	***	149.2	85.2-202	***	119.0	60.1-156	--		
LfLn	July 1999	Leaf length, sum of three leaves (cm)	***	41.6	28.5-51.4	***	35.6	21.3-45.3	***	35.0	24.8-38.2
LfltLn	July 1999	Leaflet length, sum of three leaflets (cm)	***	10.6	8.4-12.8	***	9.6	7.5-10.9	***	10.1	8.5-11.3
LfltWd	July 1999	Leaflet width, sum of three leaflets (cm)	***	4.0	3.2-4.9	***	4.0	3.3-4.9	***	4.6	4.0-5.7
NbLflt	July 1999	Number of leaflets per 3 leaves	***	55.8	42.6-68.3	***	48.4	34.3-61.0	***	42.1	30.8-49.2
NbRac	July 1999	Average number of racemes per cluster	***	3.0	2.0-3.6	**	2.9	1.9-4.1	*	2.4	1.8-3.0
NbFls	July 1999	Number of flower clusters, rating (1=0, 5>45)	***	2.2	1.0-4.1	***	2.6	1.0-4.6	***	1.2	1.0-1.6
ShtRac	July 1999	Shortest raceme in a cluster (cm)	***	5.3	2.4-8.1	***	5.2	3.0-8.4	ns	4.8	3.2-5.5
LngRac	July 1999	Longest raceme in a cluster (cm)	***	8.0	5.2-11.9	***	8.1	4.9-11.5	ns	7.8	5.0-8.6
Vig	Aug. 1998	Plant vigor rating (0=dead, 3=vigorous)	--			--			***	2.5	1.4-3.0

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

ns Trait not significantly influenced by accession (P>0.05).

†Trait not measured at this location.

‡Values are for leaf material only at Sioux Center.

Table 3. Correlations of the first four principal components (PCs) with the initial traits.

	Becker				St. Paul			
Trait†	PC 1	PC 2	PC 3	PC 4	PC 1	PC 2	PC 3	PC 4
Bmsj	**0.89**‡	0.06	-0.21	0.02	**0.88**	0.11	-0.21	0.04
Bmsa	**0.81**	0.03	0.02	-0.04	**0.88**	-0.05	-0.06	0.25
LFj	-0.59	0.49	-0.06	-0.21	-0.29	**0.72**	-0.42	-0.06
LFa	0.20	0.01	0.11	**0.82**				
ADFj	0.01	**-0.68**	0.35	0.11				
ADFa	**0.70**	-0.10	0.27	-0.57	0.46	0.16	**0.66**	0.11
CPj	0.43	0.52	0.04	0.36				
CPa	-0.36	0.27	-0.45	**0.66**	-0.42	-0.45	-0.57	0.10
NDFj	-0.38	**-0.67**	-0.06	0.04				
NDFa	0.58	-0.20	0.28	**-0.65**	0.30	0.36	**0.72**	-0.08
Ht99j	**0.95**	0.16	-0.07	-0.03	**0.89**	-0.01	-0.20	-0.12
Ht00j	**0.83**	0.27	-0.25	-0.20	**0.88**	0.11	-0.26	-0.05
Ht00a	0.56	-0.08	**-0.67**	-0.19	**0.90**	0.07	-0.26	0.11
Ht99n	**0.76**	0.51	-0.13	-0.06	**0.86**	0.27	0.02	0.04
Ht00n					**0.88**	0.25	0.06	0.05
Wd99j	**0.90**	-0.01	-0.14	0.15	**0.82**	-0.26	-0.36	0.16
Wd00j	**0.87**	-0.07	-0.34	-0.03	**0.94**	-0.05	-0.23	0.13
Wd00a	0.30	-0.32	**-0.65**	0.08	**0.90**	0.07	-0.26	0.11
Wd99n	**0.94**	0.21	-0.08	-0.09	**0.97**	-0.09	0.04	0.13

Wd00n					**0.97**	-0.11	0.02	0.13
LngSt98	**0.91**	-0.03	-0.15	-0.02	**0.96**	0.01	0.07	0.05
NGr99j					**0.92**	-0.04	-0.16	-0.03
NGr99a					**0.94**	0.00	-0.02	0.10
NGr99n	**0.72**	0.56	-0.10	-0.20	**0.82**	0.32	0.05	0.14
GS199	**0.72**	-0.32	-0.33	-0.30	**0.90**	-0.22	-0.17	-0.21
GS299	-0.58	0.16	-0.43	-0.44	-0.42	0.12	**-0.63**	-0.17
LfDr98					**-0.79**	-0.02	-0.55	-0.07
LfDr99n	**-0.60**	-0.23	**-0.60**	0.19	**-0.84**	-0.06	-0.44	-0.11
WInj99	0.12	0.44	**0.63**	-0.05	0.50	0.15	0.56	0.13
Hop98	-0.44	**0.77**	0.06	-0.17	-0.37	**0.61**	-0.33	-0.01
Hop99	**-0.74**	0.55	-0.26	-0.13	**-0.61**	**0.72**	0.02	-0.06
LfArea	0.24	**0.84**	-0.22	0.02	0.08	**0.80**	-0.13	0.17
NbFls	**0.88**	-0.26	-0.06	-0.19	**0.92**	-0.20	0.09	-0.14

†Trait descriptions are provided in Table 2.

‡Correlations <-0.60 and >0.60 are highlighted.

Table 4. Spearman-rank correlation coefficients between false indigo traits measured at three locations. Forage yield and quality traits are from the July 1999 harvest.

		Becker					St. Paul				
Location	Trait†	Biomass	Leaf	GS	NDF	CP	Biomass	Leaf	GS	NDF	CP
Becker	Biomass	1.00									
	Leaf	-0.31	1.00								
	GS	0.71 ***	-0.22	1.00							
	NDF	-0.32	0.19	-0.06	1.00						
	CP	0.26	-0.30	-0.02	-0.61 **	1.00					
St. Paul	Biomass	0.83 ***	-0.31	0.63 **	-0.28	0.24	1.00				
	Leaf	-0.15	0.60 **	-0.09	-0.11	0.05	0.07	1.00			
	GS	0.85 ***	-0.32	0.92 ***	-0.09	0.09	0.82 ***	-0.12	1.00		
	NDF	0.05	-0.12	0.32	0.58 **	-0.28	0.01	-0.11	0.29	1.00	
	CP	-0.27	0.05	-0.38	-0.27	0.31	-0.28	0.17	-0.48 *	-0.53 *	1.00
Sioux Center	Biomass	0.76 **	-0.09	0.50	-0.19	0.06	0.53	-0.32	0.52	-0.07	-0.40

Leaf	-0.64 *	0.50	-0.71 **	0.03	-0.16	-0.51	0.51	-0.71 **	-0.08	0.29 **
GS	0.89 ***	-0.34	0.83 ***	-0.36	0.28	0.80 ***	-0.15	0.90 ***	-0.05	-0.27 **
NDF	-0.82 ***	0.66 *	-0.73 **	0.22	-0.03	-0.68 *	0.57 *	-0.73 **	-0.30	0.42 *
CP	0.60 *	-0.70 *	0.73 **	-0.35	0.12	0.64 *	0.02	0.73 **	0.34	-0.30

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

†Leaf= leaf conc., GS=growth stage in June, CP=crude protein, NDF=neutral detergent fiber.

Table 4. Spearman-rank correlation coefficients between false indigo traits measured at three locations. Forage yield and quality traits are from the August 1999 harvest.

		Becker					St. Paul				
Location	Trait†	Biomass	Leaf	GS	NDF	CP	Biomass	Leaf	GS	NDF	CP
Becker	Biomass	1.00									
	Leaf	0.03	1.00								
	GS	0.70***	-0.33	1.00							
	NDF	0.61**	-0.51*	0.73***	1.00						
	CP	-0.49*	0.48*	-0.51*	-0.87***	1.00					
St. Paul	Biomass	0.78***	0.04	0.55**	0.44*	-0.38	1.00				
	Leaf	-0.02	0.17	0.25	-0.05	0.19	-0.25	1.00			
	GS	0.81***	-0.24	0.92***	0.73***	-0.55**	0.80***	0.09	1.00		
	NDF	0.31	0.04	-0.01	0.32	-0.46*	0.24	-0.53**	0.08	1.00	
	CP	-0.31	-0.02	0.04	-0.27	0.43*	-0.35	0.70***	-0.10	-0.91***	1.00
Sioux Center	Biomass	0.83***	0.14	0.71**	0.65*	-0.49	0.77**	0.08	0.79**	0.07	0.05
	Leaf	-0.65**	0.22	-0.84***	-0.85***	0.41	-0.54	-0.26	-0.86***	0.18	-0.30

GS	0.89***	0.29	0.83***	0.53*	-0.28	0.84***	0.03	0.90***	0.13	-0.13
NDF	-0.48	-0.07	-0.57*	-0.49	0.21	-0.55*	-0.34	-0.56*	0.20	-0.28
CP	0.34	-0.46	0.15	0.46	-0.28	0.07	0.32	0.16	-0.25	0.29

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

†Leaf= leaf conc., GS=growth stage in June, CP=crude protein, NDF=neutral detergent fiber.

FIGURE CAPTIONS

Fig. 1. False indigo accessions clustered by WPGMA. The seven clusters were created by selecting a cutoff of 1.08 (indicated by dashed line).

Fig. 2. Plot of the first two principal components from analysis of the false indigo traits listed in Table 3. Clusters from WPGMA analysis are labeled with roman numerals.

Fig. 3. Plot of the third and fourth principal components from analysis of the false indigo traits listed in Table 3.

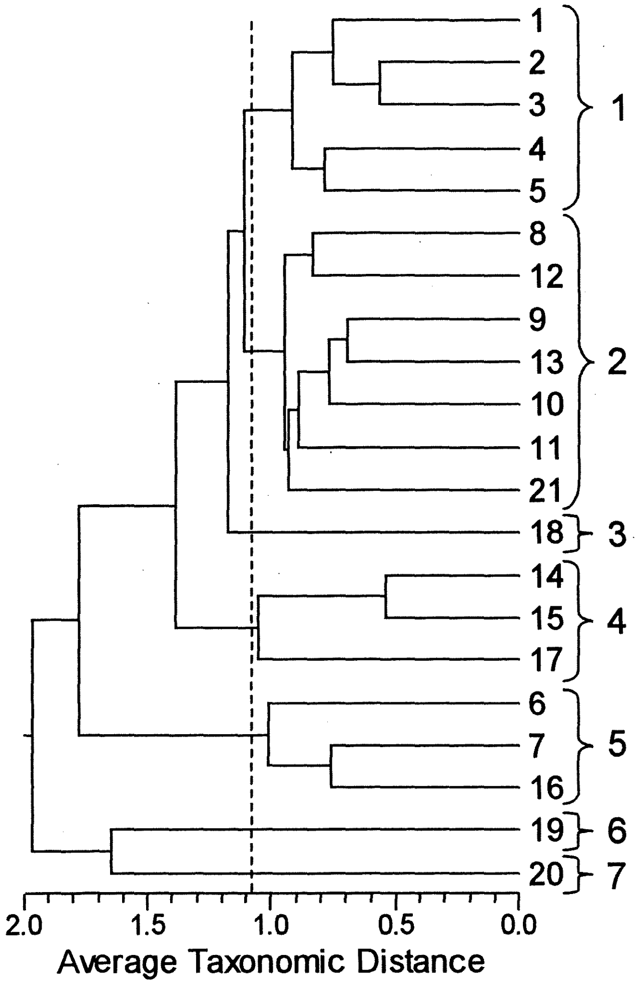

Fig. 1. False indigo accessions clustered by WPGMA. The seven clusters were created by selecting a cutoff of 1.08 (indicated by dashed line).

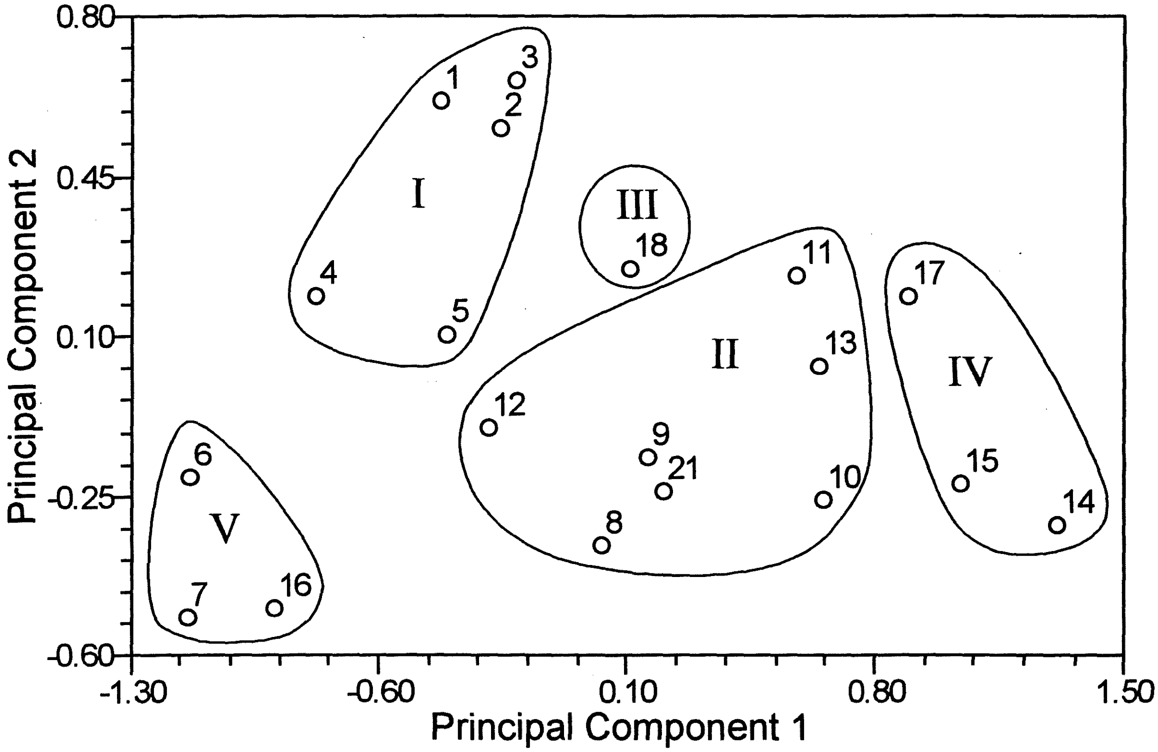

Fig. 2. Plot of the first two principal components from analysis of the false indigo traits listed in Table 3. Clusters from WPGMA analysis are labeled with roman numerals.

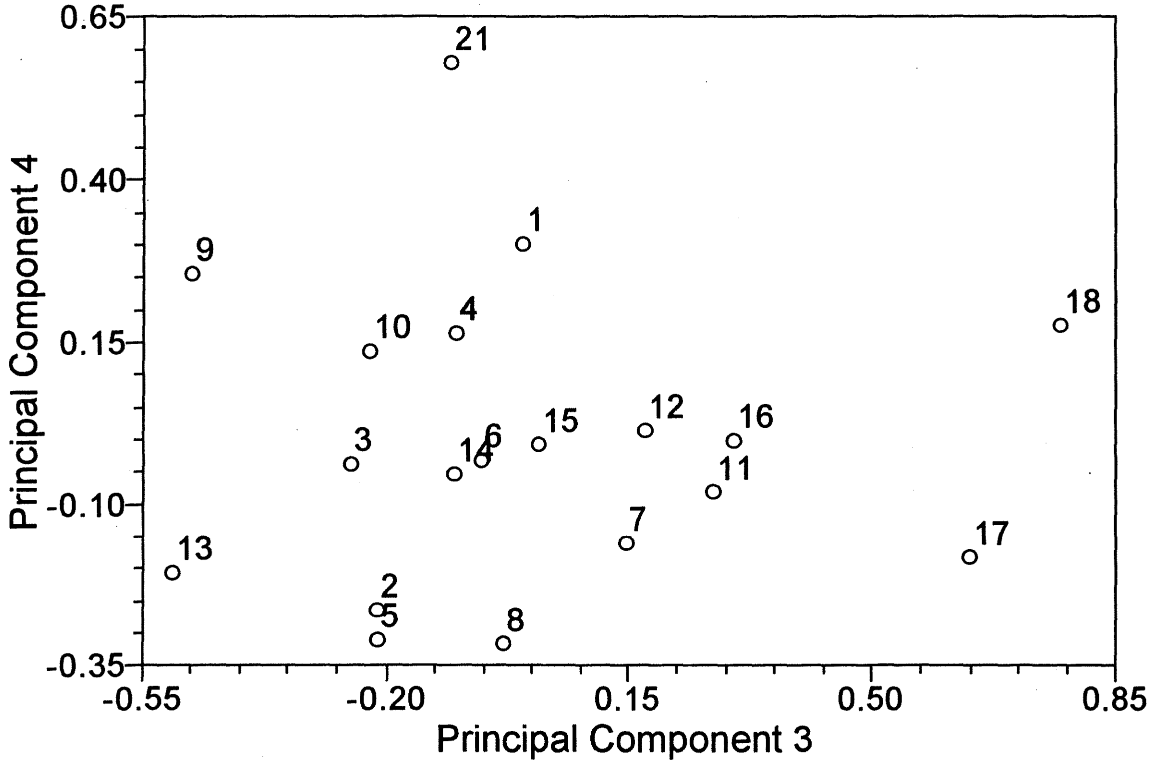

Fig. 3. Plot of the third and fourth principal components from analysis of the false indigo traits listed in Table 3.

Evaluation of Diversity Among and Within Accessions of Illinois Bundleflower

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ABSTRACT

Illinois bundleflower [*Desmanthus illinoensis* (Michx.) MacMillan] is a native herbaceous warm-season perennial legume. It is a promising perennial forage and grain crop. Success of research with the species will depend on knowledge of available genetic resources. Diversity in northern accessions of Illinois bundleflower is unknown. Our objectives were to determine: 1) the range of genetic variation for selected traits within and between northern accessions, 2) the distribution of variation among accessions, and 3) the correlations among traits. We evaluated 20 accessions at two locations and 18 accessions at a third location. Within-accession diversity was determined using a progeny test at two locations. Every measured trait was influenced by accession (P<0.05) in at least one location. Therefore, these accessions can provide the genetic diversity needed to develop varieties adapted to the northern United States. Much of the variation can be explained by latitude of origin. Southern accessions had the greatest forage and seed yield potential, were later maturing, and lacked persistence. Variation (P<0.05) for traits including seed yield and survival was also found within accessions. Within year and location, average seed CP concentration and seed weight were correlated (average r=0.71, P always <0.05), indicating that improving these traits simultaneously via selection is promising. Within location in August, forage neutral detergent fiber (NDF) was negatively correlated with leaf concentration (average r=-0.89, P always <0.001), and leaf and pod concentration were negatively correlated (average r=-0.80, P always <0.01). The correlations indicate that forage quality declines as the forage composition changes with advancing maturity.

Abbreviations: ADF, acid detergent fiber; CP, crude protein; NDF, neutral detergen fiber; NIRS, near infrared reflectance spectroscopy; PC, principal component; UPGMA, unweighted pair-group method, arithmetic average.

Illinois bundleflower is an herbaceous perennial legume native to North America. A mature plant has several erect stems growing to a height of 30 to 200 cm (Great Plains Flora Association, 1986). The species is preferred forage by all classes of livestock, and is similar in feed value to domesticated legumes (Phillips Petroleum Company, 1963). It decreases in abundance under overgrazing, and is therefore an important range condition indicator.It is found throughout the Great Plains, north to North Dakota, and south to Florida and New Mexico. It occurs most often in open wooded slopes, prairies, ravines, stream banks, roadsides, and waste places (Great Plains Flora Association, 1986). The warm-season plant is drought resistant and adapted to a wide range of soils and climatic conditions (Philips Petroleum Company, 1963).

Luckow (1993) provided a thorough botanical description of Illinois bundleflower. Leaves are bipinnate and 3.5 to 12.0 cm long. Leaflets are 1.7 to 6.0 mm long and 0.5 to 1.4 mm wide. Flowers are usually perfect and born in heads 0.6 to 1.1 cm long containing 22 to 71 flowers. Petals are pale green or white and 2.5 to 3.3 mm long. The five stamens per flower are 4.4 to 8.2 mm long. Pods are on peduncles 1.8 to 6.5 cm long bearing 8 to 35 pods. The pods are 1.5 to 3.2 cm long and 4.5 to 7.0 mm wide, containing two to five seeds. Seeds are flattened, red-brown, 3.0 to 4.5 mm long, and 2.0-3.2 mm wide. The taproot is more than 40 cm long and 0.5 to 4.0 cm in diameter. Flowering is indeterminate, occurring in May and June in the southern portion of the range and in July and August to the north. Fruiting is from July to October. Chromosome number is 2n=28.

Illinois bundleflower is a particularly valuable forage species because of its summer productivity and compatibility with warm season grasses. It has been readily established in existing kleingrass (*Panicum coloratum* L. swards, and stands persisted for the four years of the study (Dovel et al., 1990). Illinois bundleflower in biculture with three warm season grass species has increased forage yield and crude protein concentration compared to grass monocultures (Posler et al., 1993).

Illinois bundleflower is a promising perennial grain crop. Seed yields of 1700 kg ha^{-1} have been obtained from unimproved accessions (Kulakow et al., 1990). The seed contains no toxic levels of oxalates, cyanides, nitrates, or alkaloids (Kulakow et al., 1990), and has a crude protein content of about 380 g kg^{-1} (Piper et al., 1988). A multiple-use perennial grain and forage crop would provide flexibility and income for farmers while conserving natural resources (Soule and Piper, 1992).

Evaluation and selection has been performed with Illinois bundleflower accessions adapted to the southern portion of its range. The cultivar Sabine has been released for use in Texas, Oklahoma, and eastward (Muncrief and Heizer, 1985). It is useful for pasture mixes, wildlife plantings, and in revegetation of mined land. Kulakow (1999) evaluated diversity for traits related to grain production among 141 accessions obtained primarily from the Great Plains. A wide range for traits such as seed yield, seed size, shattering, and growth form led to the conclusion that the possibility of breeding Illinois bundleflower populations for use as a grain crop is promising. Accessions obtained from Texas and Oklahoma had poor survival at the study location in central Kansas. Lack of winter hardiness in accessions from slightly more southern latitudes than the study environment suggests that a separate plant breeding program utilizing adapted accessions will be required to develop varieties appropriate for the northern United States.

Diversity for agronomic traits in northern accessions of Illinois bundleflower is unknown. Knowledge of genetic variability in the species would aid in determining plant breeding priorities. Information about the characteristics of specific northern accessions would enable plant breeders to make informed decisions about crosses that would aid in achieving plant improvement goals. Our objectives were to determine the range of genetically controlled variation for selected traits within and between a representative set of northern accessions of Illinois bundleflower, to determine the distribution of variation among the accessions, and to examine the phenotypic correlations among traits.

MATERIALS AND METHODS

Experiment 1

Seeds of 20 Illinois bundleflower accessions were obtained from the northern range of the species (Fig. 1). Fifteen accessions were collected from wild populations, and five accessions were obtained from the Land Institute, Salina, KS (Table 1). The accessions were established in randomized complete block designs at three locations: St. Paul, MN; Becker, MN; and Sioux Center, IA. At St. Paul there were five replications and six plants plot^{-1}, at Becker there were 10 replications and 6 plants plot^{-1}, and at Sioux Center there were seven replications and seven plants plot^{-1}. The soil at St. Paul was a Waukegan silt loam (fine-silty over sandy, mixed, mesic Typic Hapludoll) with pH, P, K, and organic matter levels of 7.6, 256 kg ha^{-1}, 352 kg ha^{-1}, and 28 g kg^{-1}. The soil at Becker was a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) with pH, P, K, and organic matter levels of 6.6, 88 kg ha^{-1}, 165 kg ha^{-1}, and 22 g kg^{-1}. The soil at Sioux Center was a Galva silty clay loam (fine-silty, mixed, superactive, mesic Typic Hapludoll) with pH, P, K, and organic matter levels of 7.0, 224 kg ha^{-1}, 672 kg ha^{-1}, and 60 g kg^{-1}. Due to limited seed supply, only entries 1-18 were established at Sioux Center and seed of entries 18-20 was only adequate for 1 to 4 plants plot^{-1} at St. Paul and Becker.

Seeds were scarified with sandpaper and planted in 4 by 20.5 cm cones in the greenhouse in early April 1998. The containers were surface-inoculated with appropriate rhizobium (LiphaTech, Milwaukee, WI 53209) after planting. At all locations, plants were spaced 0.76 m apart in rows 1.52 m apart. Weeds were controlled with cultivation, hand weeding, mowing, and herbicide applications. Trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl) benzenamine] was applied prior to planting at Becker and Sioux Center. Plants at St. Paul in 1998 and 1999 and at Becker in 1999 were covered and the plots were treated with imazethapyr {2-[4,5-

dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid}, glyphosate [N-(phosphonomethyl) glycine], and pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine]. Plots at Sioux Center were treated with imazapic {(±)-2-[4,5-dihydro-4-methyl-4(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} in 1999 and plots at Saint Paul and Becker were treated with imazapic and pendimethalin in 2000. At Becker, irrigation was provided according to the checkbook method (Wright and Bergsrud, 1991) in 1998 and 1999, but not in 2000.

We measured 58 traits (Table 2). Most traits were measured on every plant in each plot. Biomass yield, forage quality, and forage composition were determined by cutting one plant plot^{-1} to a height of 10 cm in mid-July 1999 and cutting a second plant in each plot in mid-August. Plants were not harvested in both months from plots containing less than four plants. Harvested plants were oven-dried at 60° C for 48 hours before weighing to determine biomass yield. Growth staging was performed using a modified version of the approach of Lancashire et al. (1991). Because the staging codes are not linear, we converted the codes to ranks before performing statistical calculations. To aid interpretation, the values presented in Table 2 were obtained by converting from ranks back to the growth stage code.

Experiment 2

In 1998, seed was collected from four randomly selected plants of each accession at the Becker location of Experiment 1. Progeny from a single maternal plant comprised one treatment, which was nested within accession. Using protocol similar to Experiment One, experiments were established at St. Paul, MN, and Rosemount, MN, in 1999. There were 5 replications and 1 plant per plot in a randomized complete block design. At St. Paul, weeds were controlled with imazapic and pendimethalin. At Rosemount, weeds were controlled with trifluralin in 1999 and imazapic in 2000. In Aug.1999, plant height was measured. In Sept. 2000, plant height, plant width, seed yield, weight of 1000 seeds, and seed CP were measured. In June 2001, early growth (length of longest stem) and survival were measured.

Forage and Seed Analysis

Forage CP, NDF, ADF (Goering and Van Soest, 1970), forage composition (leaf, stem, and pod), seed CP, and seed weight in 2000 were determined using near infrared reflectance spectroscopy (NIRS). A 500-g subsample of the forage harvested from each plant in July and August 1999 was ground in a Wiley mill with a 1 mm screen. The samples were tumbled in a drum turning at 15 rpm for 20 min to obtain homogeneity. Seeds were scanned whole but ground before CP analysis of reference samples. Spectra were collected on all samples using a NIRS scanning monochromomator, model 6500 (Foss North America, Inc., Eden Prairie, MN 55344) and NIRS version 4.0 software (Infrasoft International, Port Matilda, PA 16870). Reflectance data were recorded between 400 and 2500 nm wavelengths at 2-nm intervals. Equations for leaf, stem, and pod concentrations were developed by using 50 samples that were hand separated, weighed, ground, and reconstituted. Reference procedures for all other traits were performed on 50 samples selected by the software and prediction equations were developed. The 1-VR values for the prediction equations were 0.97, 0.99, 0.98, 0.94, 0.74, 0.97, 0.90, and 0.84 for forage CP, NDF, ADF, leaf concentration, stem concentration, pod concentration, seed CP, and seed weight, respectively.

Statistical Analysis

For Experiment One, mean, maximum, and minimum values of every entry were calculated for each trait in every environment to assess the range and distribution of values for each trait. An analysis of variance (ANOVA) was performed on plot means of every trait for each environment in which it was measured using PROC MIXED (SAS Institute, 1996). Entry was treated as a fixed effect and block as random. Adjusted means were calculated for the entries at each location.

A principal component (PC) analysis was performed on standardized ((accession mean - trait mean) / standard deviation) adjusted means using only the traits that were influenced by entry (Table 2) using NTSYSpc (Rohlf, 2000). Correlations between the first three PCs and the initial traits were calculated to aid in interpretation of the analysis. To further examine relationships among selected traits, a correlation analysis was performed using Spearman-rank correlations (SAS Institute, 1990).

Cluster analysis was performed using all entries and all traits that were influenced by entry using NTSYSpc. The average taxonomic distances between all accessions were calculated from standardized ((accession mean - trait mean) / standard deviation) adjusted means using only the traits that were influenced by entry. The resulting distance matrix was used to generate a tree using the UPGMA (unweighted pair-group method, arithmetic averages) clustering procedure. An average taxonomic distance of 1.3 was selected to divide the entries into seven clusters that were consistent with the principal component analysis.

For Experiment Two, PROC MIXED was used to calculated variance components for each trait. All effects were considered random. The model consisted of the following effects: location, block within location, accession, accession by location, maternal plant within accession, and maternal plant within accession by location.

RESULTS AND DISCUSSION

Diversity Among Accessions

In Experiment 1, every measured trait was influenced by entry in at least one environment (Table 2). At Becker, 51 of 54 traits were influenced by entry, at St. Paul 38 of 51 traits were influenced by entry, and at Sioux Center all 20 traits were influenced by entry ($P<0.05$). We conclude that there is substantial genetic diversity between northern accessions of Illinois bundleflower for a wide array of morphological, agronomic, and phenological traits.

Maximum biomass yield of 562 g $plant^{-1}$ was obtained from Entry 16 at Sioux Center. At the planting density used (0.87 plants m^{-2}), this yield translates to 4.9 Mg ha^{-1}. The maxiumum yield obtained from a single August cutting of Illinois bundleflower is about 50% of yields of alfalfa cut three times per year in a similar environment (Sheaffer et al., 2000). Considering that the plant density required for maximum yield of alfalfa is about 150 times greater than the planting density used in the present study (Tesar and Marble, 1988), we conclude that the highest yielding Illinois bundleflower entries under optimal management have potential to achieve biomass yields similar to alfalfa. The importance of selection for high biomass yield is clear because the lowest yielding entry at Sioux Center yielded only 7% of Entry 16 in August. Across all three locations, average August biomass increased more than 300% compared to average July biomass, demonstrating the potential of Illinois bundleflower to supply forage in the hot summer months.

In July, location average CP, ADF, and NDF values (Table 2) were similar or superior to those of alfalfa harvested at the early flower stage (Sheaffer et al., 2000). Average leaf concentration across entries and locations in July was 644 g kg^{-1}, substantially higher than the 500 g kg^{-1} that is typical of alfalfa (Sheaffer et al., 2000).

August forage quality varied widely by location (Table 2). Plants at Becker had the lowest forage quality, which was associated with earlier maturity and leaf drop at this location. At St. Paul, average August ADF and NDF concentrations were 393 and 436 g kg^{-1}, superior to alfalfa harvested at the late flower stage (Sheaffer et al., 2000). However, CP concentration was only 150 g kg^{-1}, lower than alfalfa harvested at the late flower stage [about 170 g kg^{-1} (Sheaffer et al., 2000)]. August forage quality was the highest at Sioux Center. Entry 16, which had the highest August biomass yield, had CP, ADF, and NDF concentrations of 190, 353, and 394 g kg^{-1}, which is similar to alfalfa harvested at the early flower stage (Sheaffer et al., 2000). High August forage quality at Sioux Center was probably due to slow late-season development at this location. In August, average pod concentration at Sioux Center was only 179 g kg^{-1}, compared to 430 g kg^{-1} at Becker. These results indicate that harvesting Illinois bundleflower when the pod concentration is about 180 g kg^{-1} may optimize forage yield and quality.

Seed yield in 1998 at St. Paul and Becker averaged 43.6 g $plant^{-1}$, and increased in the following two years at these locations (Table 2). Highest seed yields were in 1999 at Sioux Center. Entry 16 had the highest seed yield at this location, 194 g $plant^{-1}$. This yield corresponds to 1.7 Mg ha^{-1}. Maximum seed yield recorded by Kulakow (1999) in Kansas was also 1.7 Mg ha^{-1}, but in the first year rather than the second. Average second year seed yield across accessions and locations was 0.7 Mg ha^{-1}, similar to the average seed yield of 0.6 Mg ha^{-1} obtained with primarily southern accessions in Kansas. These results indicate that seed yield of Illinois bundleflower is not lower in the northern range of its distribution, although an establishment year is required to obtain maximum seed yield in this region. Maximum seed yields may be substantially higher at higher planting densities.

Average seed yield at Becker in 2000 in the absence of irrigation was 72.8 g $plant^{-1}$. This yield is nearly equal to seed yield the previous year when irrigation was supplied. The highest yielding accession produced the equivalent of 1.1 Mg ha^{-1} at Becker with no irrigation. For comparison, dryland soybean [*Glycine max* (L.) Merr.] at the same location yielded about 1.4 Mg ha^{-1} and irrigated soybean yielded about 3.4 Mg ha^{-1} (J.H. Orf, personal communication, 2001). These results indicate that seed yield of Illinois bundleflower may be more stable than annual crops like soybean in dry environments. Illinois bundleflower is therefore most likely to be economically successful as a grain crop in regions that are frequently subject do drought.

Average seed weight in 1999 was 5.7 g 1000 $seeds^{-1}$, similar to the average seed weight of 6.1 g 1000 $seeds^{-1}$ with southern accessions (Kulakow, 1999). The range in seed size across locations was 4.8 to 6.9 g 1000 $seeds^{-1}$, whereas southern accessions had a range from 4.3 to 9.7 g 1000 $seeds^{-1}$ (Kulakow, 1999). Southern accessions contain greater variation for seed size and will be an important source of diversity for improving this trait.

Seed CP concentration within northern Illinois bundleflower accessions was less than reported previously for southern accessions. Average CP concentration across entries and locations in 1999 was 328 g kg^{-1}, whereas the range for southern accessions was previously reported as 36.7 to 38.9 g kg^{-1} (Piper et al., 1988). Southern accessions may be an important source of diversity for improving the CP content of seed or northern environments may limit seed CP concentration. For comparison, the average CP concentration of soybeans grown in central Minnesota is about 360 g kg^{-1} (Pazdernik et al., 1997).

Survival varied widely by accession and location. In 1999, survival was not rated at Becker because there was no plant loss. At St. Paul in 1999, survival ranged from 13 to 97%. Survival of plants cut in July was consistently higher than survival of plants cut in August, indicating that earlier forage harvests should increase stand persistence. At St. Paul, entries 3, 7, and 19 all had survival in 2001of August-cut plants of 80% or higher. Therefore, selection for persistence under grazing is promising.

Cluster and Principal Component Analysis

Cluster analysis by UPGMA (Fig. 2) provided an adequate grouping of the accessions (cophenetic correlation=0.74). Accessions within the major clusters were derived from similar geographic origins (Fig. 1). Accessions in Cluster 1 originated from southern and eastern South Dakota and adjacent regions of Iowa and Minnesota. Cluster 2 accessions were obtained from ≤42° N latitude. The single accession in Cluster 3 came from eastern Iowa. Accessions in Cluster 4 were derived from a localized region of west-central Minnesota and adjacent South Dakota, with one accession from south-central North Dakota. The clear agreement of the clusters with geographical origin indicates that additional collections from other regions would be likely to provide further diversity for plant breeding. Regions that were under-represented in the current study, such as central Iowa and eastern Minnesota, should be targeted for additional collecting. Further support for collecting from new regions to enhance available diversity is that the geographic distances between accessions were correlated with the taxonomic distances (r=0.55, P<0.001). The correlation indicates that geographically adjacent accessions will be more similar than geographically distant accessions.

The first three PCs explained 44.9, 14.0, and 8.5% of the variance, respectively. In total, the first three PCs explained 66.9% of the variance. Most traits were correlated (r>0.55 or r<-0.55, P<0.05) with one of the first three PCs (Table 3).

All but Clusters 2 and 3 were clearly separated by the first two PCs (Fig.3), and Cluster 3 was clearly separated from all others by the first and third PCs (Fig. 4). Clusters that are separated by a given PC will differ for traits highly correlated with that PC. Most traits were well correlated with at least one of the first three PCs. Therefore, positions of the clusters on the plots of the first three PCs can be used to infer relative values for many traits. Accessions in Cluster 4 had very low values for PC 1, so these accessions are generally early maturing, have short stems, have low first-year vigor, and have a high survival rate. Accessions in Clusters 2 and 3 had the highest values for PC 1, indicating that they were late maturing, had low survival, and had the highest biomass and seed yields at Sioux Center. The first PC was well correlated with latitude of accession origins ($r=-0.88$, $p<0.001$), which indicates that the late maturity, low survival, and occasionally high yields of accessions in Clusters 2 and 3 was probably due to their southern origin. Cluster 1 accessions were intermediate for many traits, having moderate winter survival, intermediate maturity, and average seed and forage yields. Cluster 3, consisting only of Accession 15, was clearly separated from all other accessions by PC 3, indicating that this cluster is extreme for traits well correlated with PC 3, such as seed CP in 2000.

Many traits had similar PC correlations across all three locations, indicating that for these traits location by accession interactions were small. In instances where PC correlations differ by location, we can use the PC analysis to examine the interaction between accessions and locations. At Sioux Center, All but two traits were well correlated with the first principal component. At this location, first-year vigor appeared to have an overwhelming influence on almost all other traits. Accessions with large values for PC1 had good first-year vigor and continued to be the largest and most rapidly developing in the following year. Growth of accessions that were early maturing at other locations appeared slowed by low first-year vigor at Sioux Center. At Becker and St. Paul, seed yield was correlated with PC1 in 1998. However, in 1999, seed yield at St. Paul was correlated with PC2 and in 2000 seed yield at Becker was correlated with PC2. These changes most likely occurred because of winter injury to accessions with the highest values for PC1. We conclude that in the absence of winter injury the southern accessions with high values for PC1 have the highest potential for seed yield, but when winter injury occurs accessions with high values for PC2 will generally produce the most seed.

Correlation Analysis

Forage yield, forage quality, seed yield, and seed quality traits were often not well correlated with one of the first three PCs. Therefore, relationships among these traits cannot be easily determined from the PC analysis. To examine relationships among these traits, Spearman-rank correlations were calculated.

Correlations of seed yields across locations and years were not consistent. At Becker, seed yields were correlated across years (average r=0.65, P<0.01), but there were no correlations across years at St. Paul. Lack of correlations across years at St. Paul was probably due to winter injury. Across locations within years, Saint Paul yields were correlated with Becker yields in 1998 (r=0.73, P<0.001) and 2000 (r=0.48, P<0.05). Instances where correlations in seed yield are low can often be explained by differences in winter injury. Therefore, selecting for survival will be an important means of insuring consistent seed yield in Illinois bundleflower in northern environments.

Seed CP concentration of accessions was generally well correlated across both years and locations with the exception of seed produced at Becker in 1999. The seed CP from this year and location was not positively correlated with any other year or location. If Becker 1999 is excluded, seed CP of all other years and locations was correlated (average r=0.66, P always <0.01). We conclude that breeding for consistently high seed CP across locations would be a reasonable objective, although there may be anomalous environments.

To examine the influence of seed yield and seed weight on seed CP, we calculated correlations for these traits within each year and location. Within year and location, seed CP was always correlated with seed weight (average *r*=0.71, *P* always <0.05). The strong positive correlation indicates that selection for seed weight would be likely to have a positive influence on seed CP. Within year and location, seed yield was only negatively correlated with seed CP at St. Paul and Becker in 1998 (average *r*=-0.78, *P* always <0.001). Lack of correlations between seed yield and seed CP in the second and third years indicates that selection for seed yield in mature plants would not necessarily produce a correlated reduction in seed CP.

Correlations were calculated between biomass yield, forage CP, NDF, and forage composition (leaf, stem, and pod) within and among locations within the July and August harvests. For both harvests, none of these traits were consistently correlated across locations. Lack of correlation across locations indicates that selection for these traits in multiple environments might be difficult. However, the lack of correlation across location could have been due to different maturities at the three locations. Within location in July, biomass yield (average *r*=0.73, *P* always <0.05) and leaf concentration (average *r*=-0.75, *P* always <0.05) were correlated with NDF. Within location in August, leaf concentration was correlated with NDF (average *r*=-0.89, *P* always <0.001) and forage CP (average *r*=0.67, *P* always <0.05), and pod concentration was correlated with leaf concentration (average *r*=-0.80, *P* always <0.01). These correlations indicate that forage quality declines as the forage composition shifts toward increased pod concentration with advancing maturity. We conclude that the leaf and pod concentrations of Illinois bundleflower forage strongly influence forage quality. Forage composition should be considered in future plant breeding or agronomic studies with the species.

Diversity Within Accessions

Experiment 2 evaluated progeny of four maternal parents from each accession used in Experiment 1. If we assume 100% self-pollination, progeny of maternal plants (families) would be genetically identical. In this case, differences between families from different maternal plants within an accession would estimate within-accession diversity. Because Illinois bundleflower is about 80% self-pollinating (unpublished data, 2000), we used this technique as a conservative estimate of within-accession diversity.

We found within-accession diversity for six of eight measured traits (Table 4). Within-accession diversity for survival was significant (P<0.05). This surprising result indicates that selection within southern populations could improve survival when planted farther north. Seed yield had significant within-accession diversity, but between-accession diversity was not significant. Therefore, selection for seed yield could be successfully performed within accessions that have other desirable traits. For height in 1999 and 2000, only 16 and 12% of the genetically controlled variance was within accession. Selection for plant height within accession would produce limited gains compared to selection for plant height between accessions. For seed weight and seed CP, 29 and 36% of the genetically controlled variance was within accession. Relatively high within-accession diversity for these traits indicates that they could be improved by selection both between and within accessions.

DeHaan et al. (*in preparation*) have studied within- and between-accession genetic diversity in Illinois bundleflower using AFLP molecular markers. An analysis of molecular variance (Excoffier et al., 1992) indicated that 57% of the diversity in northern accessions of Illinois bundleflower was within accessions. A second statistic, the within-accession diversity estimate, (Nei, 1973) calculated for northern populations indicated that 31% of the diversity was within accessions. Across all traits measured in Experiment 2, 33% of the genetically controlled variance was found within accession. In this case, Nei's diversity estimate provided a more accurate prediction of measurable morphological diversity within accessions than did the analysis of molecular variance.

CONCLUSIONS

Variation is present among northern Illinois bundleflower accessions for traits including forage yield, growth form, maturity, survival, seed yield, seed size, and seed CP concentration. We conclude that the accessions we evaluated could provide much of the genetic diversity required for improving the performance of Illinois bundleflower as a perennial grain or forage crop in the north central United States. The seed and forage yield and forage quality of unimproved accessions is remarkably high, indicating Illinois bundleflower could become an economically important species with limited requirements for prior plant breeding.

Much of the variation between northern Illinois bundleflower accessions can be explained by latitude of origin. The first PC was highly correlated with latitude of origin and explained 44.9% of the total variance. Accessions from lower latitudes have the greatest forage and seed yield potential, are late maturing, and often lack persistence. Accessions from higher latitudes are typically less productive and more persistent. Because geographic diversity was associated with phenotypic diversity of accessions, collections should be made from under-represented geographic regions to increase the available genetic diversity. Although these generalities are useful, they must not be overstated. Even among accessions from South Dakota there is a wide range of seed yield. Tables of the adjusted accession means and their standard errors for all measured traits are available (www.ibf.edu) and will provide a more complete description of the variation among accessions. Substantial diversity for traits including seed yield and survival also exists within accession, indicating that these traits could be improved by selecting from within accessions that are otherwise desirable.

Awareness of the associations among traits in Illinois bundleflower will be valuable in planning future work with the species. Seed yield was associated with lower winter injury in many environments. Therefore, slection for survival will be an important means to insure consistent seed yield. Seed CP concentration was correlated across most environments, indicating that this trait could be readily improved in varieties planted across a wide geographic range. The strong correlation between seed size and seed CP concentration indicates that selection should be effective in increasing both traits simultaneously. Seed yield and seed CP were never negatively correlated in the second or third years, an indication that increasing both traits via plant breeding has a high probability of success. Leaf and pod concentration were correlated with forage quality traits. Changes in forage composition with advancing maturity will impact forage quality and must be considered in future agronomic and plant breeding research.

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Table 1. Illinois bundleflower accession information.

Entry Number	Accession Indentifier†	North Latitude	West Longitude	County	State
1	PNL532	44.25	95.88	Lyon	MN
2	PNL533	45.59	96.49	Traverse	MN
3	PNL534	45.54	96.09	Stevens	MN
4	PNL535	45.50	96.00	Stevens	MN
5	PNL536	45.39	96.14	Big Stone	MN
6	PNL537	45.83	96.12	Grant	SD
7	PNL538	45.41	97.33	Day	SD
8	PNL539	43.49	95.10	Dickenson	IA
9	PNL540	45.27	98.75	Edmonds	SD
10	PNL541	44.77	98.70	Spink	SD
11	PNL542	42.71	96.80	Union	SD
12	PNL543	43.56	100.73	Mellette	SD
13	PNL550	46.03	100.08	Emmons	ND
14	PNL544	42.00	89.20	Ogle	IL
15	PNL545	42.47	90.66	Dubuque	IA
16	LI1046	38.81	89.55	Bond	IL
17	LI1098	40.71	99.13	Buffalo	NE
18	LI1132	40.73	98.83	Buffalo	NE
19	LI1134	45.32	96.45	Big Stone	MN

20	LI1062	41.88	87.61	Cook	IL

†Accession origin: PNL=University of Minnesota Native Perennial Legume Collection, LI=The Land Institute, Salina, KS.

Table 2. Traits measured on Illinois bundleflower accessions at three locations, significance of accession effects, and range and mean of accession means.

			Becker			**Saint Paul**			**Sioux Center**		
Trait	**Date**	**Description**	**Entry**	**Mean**	**Range**	**Entry**	**Mean**	**Range**	**Entry**	**Mean**	**Range**
BmsJ	July 1999	Biomass yield (g plant^{-1})	***	138	82.8-181	NS	78.8	27.9-139	***	52.6	16.9-101
BmsA	Aug. 1999	Biomass yield (g plant^{-1})	*	395	295-495	NS	283	108-456	***	267	39.0-562
ADFj	July 1999	Forage acid detergent fiber (g kg^{-1})	**	319	285-351	NS	258	214-302	***	262	184-319
ADFa	Aug. 1999	Forage acid detergent fiber (g kg^{-1})	NS	444	415-480	NS	393	335-437	***	303	221-378
NDFj	July 1999	Forage neutral detergent fiber (g kg^{-1})	*	364	333-409	***	311	263-359	***	265	165-317
NDFa	Aug. 1999	Forage neutral detergent fiber (g kg^{-1})	**	493	444-535	NS	436	333-501	***	333	244-394
CPj	July 1999	Forage crude protein (g kg^{-1})	***	168	151-190	*	192	166-236	***	241	209-298
CPa	Aug. 1999	Forage crude protein (g kg^{-1})	*	119	106-133	NS	150	125-175	***	218	183-265
LfJ	July 1999	Forage leaf concentration (g kg^{-1})	***	587	543-658	NS	699	628-750	***	647	562-715
LfA	Aug. 1999	Forage leaf concentration (g kg^{-1})	***	200	128-310	**	311	159-454	***	473	325-646
StA	Aug. 1999	Forage stem concentration (g kg^{-1})	***	370	287-484	*	405	305-561	***	351	252-421
PdA	Aug. 1999	Forage pod concentration (g kg^{-1})	***	430	205-540	***	302	63.4-513	***	179	67.4-286
SdY98	Oct. 1998	Seed yield (g plant^{-1})	***	34.4	8.12-61.0	***	52.8	9.78-99.5	--†		
SdY99	Oct. 1999	Seed yield (g plant^{-1})	***	70.6	42.4-97.1	**	59.2	32.7-108	***	104	53.9-194

SdY00	Oct. 2000	Seed yield (g $plant^{-1}$)	***	72.8	29.7-130	***	54.9	24.3-108	--		
SdWt98	1998	Seed weight (g 1000 $seeds^{-1}$)	***	6.66	5.79-7.47	***	5.77	4.59-6.52	--		
SdWt99	1999	Seed weight (g 1000 $seeds^{-1}$)	***	5.52	4.96-6.17	***	5.62	4.76-6.28	***	6.06	4.89-6.85
SdWt00	2000	Seed weight (g 1000 $seeds^{-1}$)	***	5.69	4.93-5.98	***	5.94	5.21-6.28	--		
SdCP98	1998	Seed crude protein (g kg^{-1})	***	337	299-363	***	350	314-376	--		
SdCP99	1999	Seed crude protein (g kg^{-1})	***	302	282-332	NS	321	305-338	***	360	343-372
SdCP00	2000	Seed crude protein (g kg^{-1})	***	323	301-345	***	351	333-371	--		
Mat98	July 1998	Maturity (1=veg., 3=flower, 5=pod)	***	2.73	1.10-4.03	***	1.99	1.07-3.24	--		
LtFl	Aug. 1998	Late flowering (1=buds, 5=no flowers)	***	3.24	1.00-5.00	***	3.36	1.00-4.79	--		
PdRp	Sept. 1998	Pod Ripening (1=none, 5=100%)	***	1.99	1.15-3.23	***	4.03	2.26-4.97	--		
Sen	Sept. 1998	Senescence (1=no leaf drop, 5=100%)	***	2.84	1.06-3.71	***	3.61	1.96-4.67	--		
GS199	July 1999	Growth Stage	***	5.5	5.1-5.7	***	5.5	3.9-5.7	***	5.5	3.9-5.7
GS299	Aug. 1999	Growth Stage	***	8.0	7.5-8.5	***	7.5	6.9-8.1	--		
EGr	May 1999	Early growth, longest stem length (cm)	***	8.91	5.25-11.2	**	11.9	8.75-16.0	***	10.6	4.54-14.7
LfDr	Aug. 1999	Lower leaf drop (cm from crown)	***	67.0	46.0-83.5	***	51.2	27.0-68.3	--		
Ht99J	Aug. 1999	Height of plants cut in July 1999 (cm)	***	58.8	37.9-80.0	***	62.9	26.0-100	--		
Ht99N	Aug. 1999	Height of never-cut plants (cm)	***	116	56.5-167	NS	94.2	69.3-107	--		
Ht00J	Aug. 2000	Height of plants cut in July 1999 (cm)	***	97.6	50.5-138	***	110	58.0-160	--		
Ht00N	Aug. 2000	Height of never-cut plants (cm)	***	91.2	47.1-117	***	107	67.8-125	--		

Wd99J	Aug. 1999	Width of plants cut in July 1999 (cm)	*	77.9	63.9-93.3	*	83	26.0-152	--		
Wd99N	Aug. 1999	Width of never-cut plants (cm)	***	145	116-183	NS	138	105-164	--		
Wd00J	Aug. 2000	Width of plants cut in July 1999 (cm)	NS	153	111-181	NS	149	102-195	--		
Wd00N	Aug. 2000	Width of never-cut plants (cm)	***	148	95.8-181	*	139	93.5-185	--		
StLn98	July 1998	Stem length (cm)	***	60.6	19.8-91.0	--			***	27.2	11.3-46.0
StLn99J	Sept. 1999	Stem length, plants cut July 1999 (cm)	***	64.3	46.6-94.2	***	68.0	28.0-108	--		
StLn99N	Sept. 1999	Stem length, never-cut plants (cm)	***	122	84.5-175	*	109	93.7-125	--		
NbSt	Aug. 1999	Number of stems from crown	***	13.5	6.35-17.5	***	9.66	5.64-12.8	***	3.23	1.61-4.75
BdlWt	Sept. 1998	Weight of one bundle (g)	***	1.00	0.68-1.37	--			--		
NbPod	Sept. 1998	Number of pods per bundle	***	30.9	16.8-39.9	--			--		
PodLn	Sept. 1998	Length of five pods (cm)	***	17.0	15.2-20.7	--			--		
PodWd	Sept. 1998	Width of five pods (cm)	***	6.15	5.36-6.80	--			--		
PedLn	Sept. 1998	Length of one peduncle (cm)	***	5.04	4.13-5.80	--			--		
Deh	Sept. 1998	Dehiscence rating (1=none, 5=100%)	***	4.61	3.13-5.00	--			--		
LfLn	July 1999	Length of three leaves (cm)	***	24.0	18.2-28.6	***	26.0	22.4-28.7	--		
LfWd	July 1999	Width of three leaves (cm)	***	21.5	17.6-25.2	***	23.9	20.5-26.5	--		
NbPn	July 1999	Number of pinnae on three leaves	***	77.8	65.3-92.7	***	71.6	53.9-79.2	--		
Vig	Sept. 1998	Vigor (1=dead, 5=vigorous)	***	4.62	3.00-5.00	***	4.65	3.00-5.00	***	4.08	1.86-4.9
Sv99	July 1999	Survival, proportion of plants still alive	--			***	0.68	0.13-0.97	--		

Sv00J	July 2000	Survival, plants cut July 1999	***	0.43	0.00-0.88	NS	0.91	0.60-1.00	--
Sv00A	July 2000	Survival, plants cut August 1999	NS	0.02	0.00-0.11	***	0.22	0.00-1.00	--
Sv00N	July 2000	Survival, never-cut plants	***	0.63	0.16-0.88	***	0.56	0.07-0.95	--
Sv01J	July 2001	Survival, plants cut July 1999	--			NS	0.85	0.50-1.00	--
Sv01A	July 2001	Survival, plants cut August 1999	--			***	0.21	0.00-1.00	--
Sv01N	July 2001	Survival, never-cut plants	--			***	0.47	0.00-0.95	--

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

ns Trait not significantly influenced by accession (*P*>0.05).

†Trait not measured at this location.

Table 3. Correlations of the first four principal components (PCs) with the original Illinois bundleflower traits.

	Becker			Saint Paul			Sioux Center		
Trait†	PC1	PC2	PC3	PC1	PC2	PC3	PC1	PC2	PC3
BmsJ	0.32	**0.74‡**	0.13				**0.87**	0.05	-0.38
BmsA	**0.65**	0.34	0.11				**0.85**	-0.04	-0.14
ADFj	**0.59**	**0.58**	0.29				**0.88**	0.11	-0.27
ADFa							**0.94**	-0.04	-0.05
NDFj	0.46	**0.62**	0.29	-0.20	**0.57**	0.30	**0.87**	0.17	-0.21
NDFa	-0.46	0.45	**0.56**				**0.93**	-0.03	-0.09
CPj	-0.47	-0.09	-0.27	**0.55**	-0.31	-0.05	**-0.86**	-0.09	0.30
CPa	0.13	-0.29	-0.42				**-0.92**	0.06	0.10
LfJ	-0.54	-0.44	-0.18				**-0.90**	0.08	0.28
LfA	0.54	-0.52	-0.29	**0.66**	-0.16	-0.02	**-0.84**	0.03	0.28
StA	**0.83**	-0.18	0.26	**0.67**	-0.23	-0.02	**0.88**	0.01	0.23
PdA	**-0.80**	0.38	-0.01	**-0.75**	0.22	0.08	0.39	-0.06	-0.49
SdY98	**0.87**	0.29	-0.02	**0.88**	0.24	-0.11			
SdY99	**0.71**	0.19	0.12	-0.20	**0.71**	-0.14	**0.59**	-0.14	-0.25
SdY00	0.46	**0.56**	**-0.63**	0.27	0.27	-0.15			
SdWt98	**-0.78**	0.15	-0.41	**-0.77**	0.35	-0.25			
SdWt99	0.13	-0.05	**-0.66**	-0.52	0.28	-0.51	**-0.55**	0.21	-0.32
SdWt00	-0.40	0.46	-0.33	**-0.62**	0.51	-0.33			

SdCP98	**-0.90**	0.17	-0.26	**-0.93**	0.23	-0.13			
SdCP99	0.50	-0.39	-0.19				-0.44	0.49	-0.40
SdCP00	-0.28	0.18	**-0.74**	-0.40	0.21	**-0.56**			
Mat98	**0.74**	0.50	-0.28	0.30	**0.57**	-0.53			
LtFl	**-0.76**	0.51	0.05	**-0.73**	0.54	0.05			
PdRp	0.19	**0.71**	-0.39	**-0.70**	0.50	-0.15			
Sen	0.04	**0.88**	0.17	-0.28	**0.87**	-0.10			
GS199	**-0.77**	0.38	-0.21	**-0.93**	0.12	-0.13	**0.62**	0.28	-0.31
GS299	**-0.89**	0.32	-0.19	**-0.94**	-0.02	-0.12			
EGr	0.24	**0.73**	0.28	**-0.72**	0.27	0.08	**0.81**	0.22	0.03
LfDr	-0.13	**0.78**	0.08	**-0.64**	0.29	0.24			
Ht99J	**0.88**	0.28	-0.23	**0.81**	0.09	-0.20			
Ht99N	**0.87**	0.07	0.25						
Ht00J	**0.82**	0.39	0.16	**0.82**	0.24	0.24			
Ht00N	**0.66**	0.35	0.47	**0.69**	0.07	-0.08			
Wd99J	0.09	0.28	**-0.70**	0.49	0.11	-0.09			
Wd99N	**0.87**	-0.01	0.00						
Wd00N	0.37	**0.63**	-0.07	0.03	**0.57**	0.20			
StLn98	**0.90**	0.32	0.06				**0.91**	-0.04	-0.27
StLn99J	**0.90**	0.00	-0.40	**0.80**	0.01	-0.20			
StLn99N	**0.91**	-0.03	0.28	0.37	0.14	**0.58**			
NbSt	0.44	**0.72**	0.02	-0.28	**0.59**	0.16	**0.79**	-0.05	-0.20

BdlWt	**0.82**	0.31	0.13						
NbPod	**0.84**	0.29	0.32						
PodLn	0.28	0.32	**-0.68**						
PodWd	-0.51	-0.02	-0.40						
PedLn	**0.64**	0.49	0.15						
Deh	-0.14	-0.12	-0.54						
LfLn	0.13	0.44	0.27	-0.39	0.43	0.10			
LfWd	0.49	-0.09	-0.03	0.29	0.20	0.46			
NbPn	-0.04	0.47	0.34	**-0.55**	0.09	-0.21			
Vig	**0.73**	0.46	-0.09	**0.63**	**0.55**	-0.16	**0.91**	0.16	-0.08
Sv99				**-0.82**	0.31	0.20			
Sv00J	**-0.83**	-0.15	0.21						
Sv00A				**-0.72**	-0.31	-0.14			
Sv00N	**-0.69**	**0.56**	0.26	**-0.86**	0.29	0.02			
Sv01A				**-0.67**	-0.33	-0.12			
Sv01N				**-0.89**	0.32	-0.08			

†Trait descriptions are provided in Table 2.

‡Correlations <-0.55 and >0.55 are highlighted.

Table 4. Variance component estimates for Illinois bundleflower families grown at two locations. Traits measured were: seed yield, seed weight, seed crude protein, height, and width in 2000; height in 1999; and early growth and survival in 2001.

Variance Component	SdYield	SdWeight	SdCP	Height99	Height00	Width	EarlyGrth	Survival
Location	4.469	0.001	0.036	0.1	95.5	1030.0	7.10	0.000
Loc(Block)	0.023	0.002	0.029	0.4	2.2	0.0	0.13	0.000
Accession	0.149	0.082*	0.500*	289.0**	256.1**	34.3	3.85	0.031***
Loc*Acc	0.130	0.007	0.050	3.6	39.8*	61.9	4.23	0.000
Acc(Parent)	0.327*	0.034***	0.278***	56.1***	36.4**	48.2	1.02	0.009*
Loc*Acc(Parent)	0.149	0.005	0.000	0.0	13.0	33.5	2.11	0.000
Residual	2.486***	0.145***	1.633***	283.3***	241.2***	697.7***	33.78***	0.106***

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

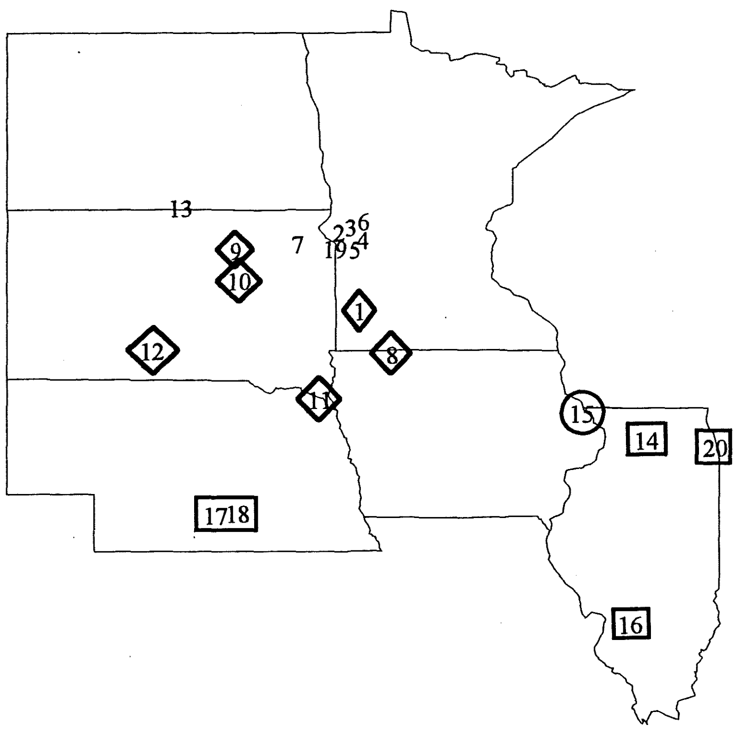
FIGURE CAPTIONS

Fig. 1. Approximate locations of Illinois bundleflower entry origins. Clusters from UPGMA analysis are represented by shapes: Cluster 1, diamond; Cluster 2, square; Cluster 3, circle; Cluster 4, none.

Fig. 2. Illinois bundleflower entries clustered by UPGMA. The four clusters were created by selecting a cutoff of 1.3 (indicated by dashed line).

Fig. 3. Plot of the first two principal components from analysis of Illinois bundleflower traits listed in table 3. Clusters from UPGMA analysis are labeled with roman numerals.

Fig. 4. Plot of the first and third principal components from analysis of Illinois bundleflower traits listed in Table 3. Clusters from UPGMA analysis are labeled with roman numerals.



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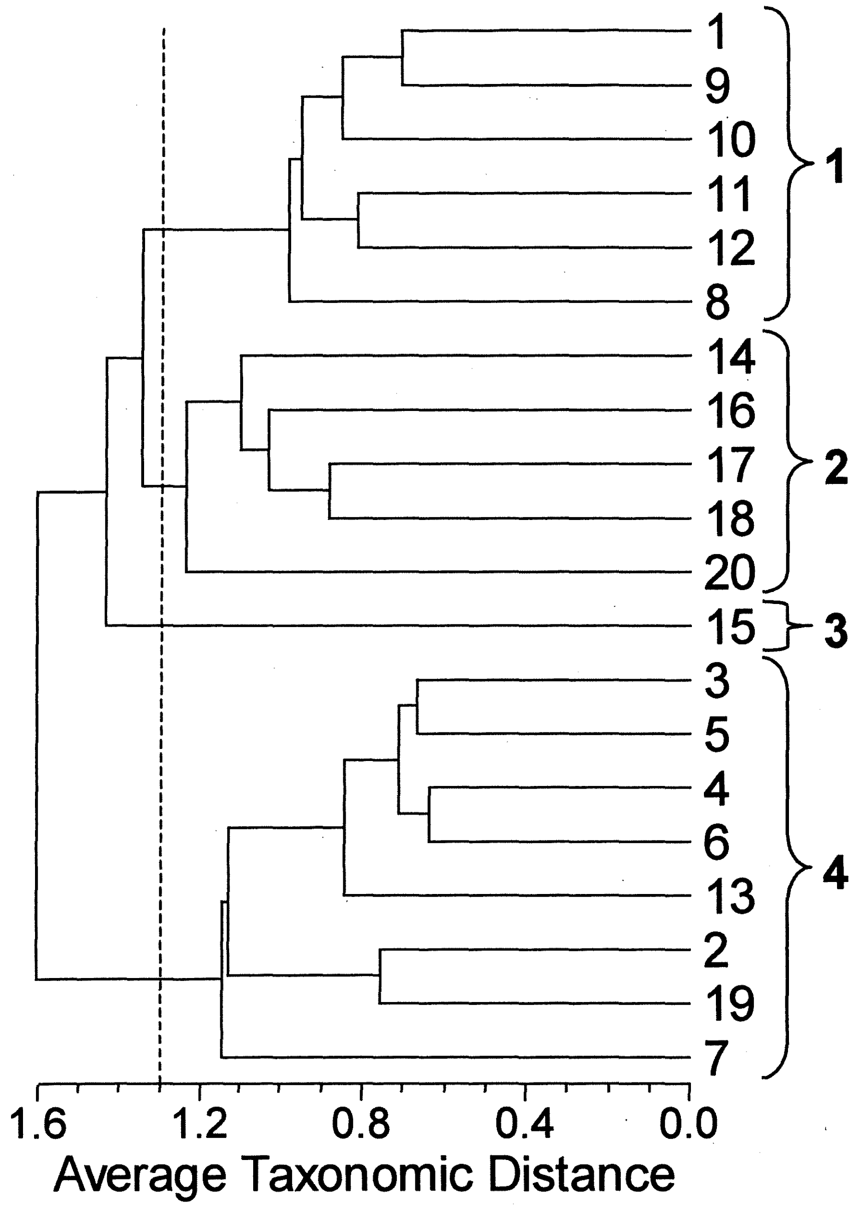

Fig. 2. Illinois bundleflower entries clustered by UPGMA. The four clusters were created by selecting a cutoff of 1.3 (indicated by dashed line).

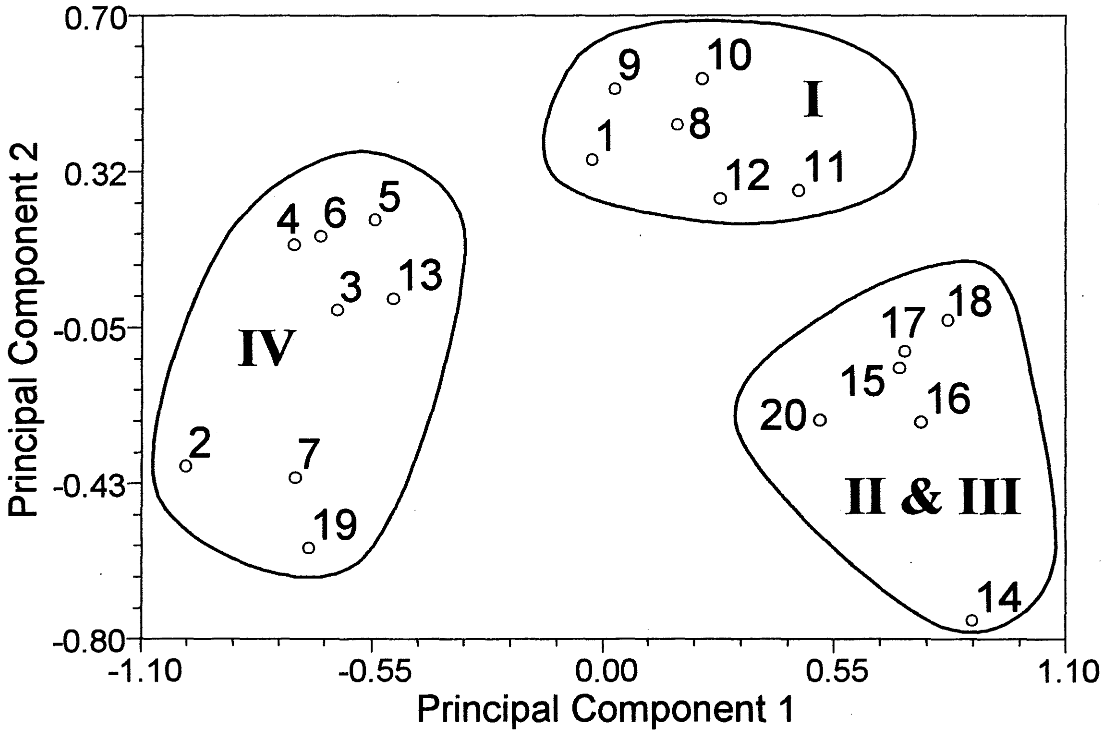

Fig. 3. Plot of the first two principal components from analysis of Illinois bundleflower traits listed in table 3. Clusters from UPGMA analysis are labeled with roman numerals.

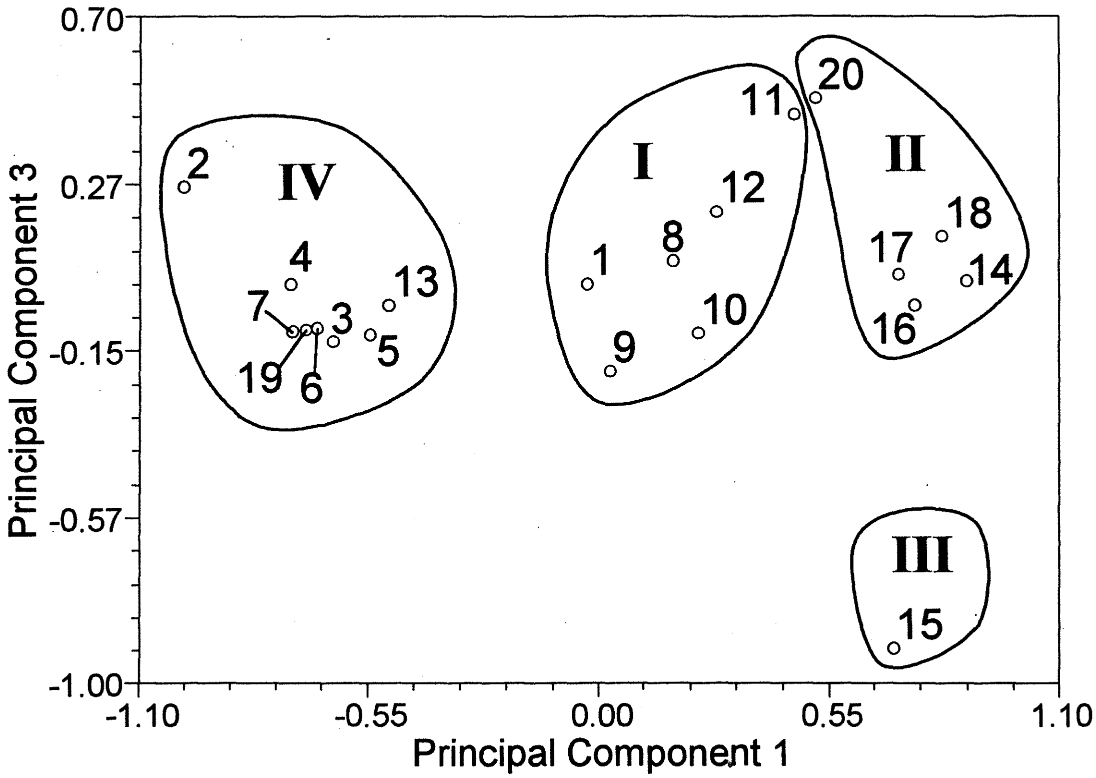

Fig. 4. Plot of the first and third principal components from analysis of Illinois bundleflower traits listed in Table 3. Clusters from UPGMA analysis are labeled with roman numerals.